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Biocoenosis and thanatocoenosis of diatoms in a Western Galician Ría

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Complete List of Authors:	Bernardez, Patricia; Instituto de Investigaciones Marinas, Grupo de Biogeoquímica Marina Varela, Manuel; Instituto Español de Oceanografía, Centro Costero de A Coruña Pazos, Yolanda; Instituto Tecnolóxico para o Control do Medio Mariño de Galicia, INTECMAR Prego, Ricardo; Instituto de Investigaciones Marinas, Grupo de Biogeoquímica Marina Francés, Guillermo; Universidade de Vigo, Departamento de Geociencias Marinas y Ordenación del Territorio
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Grupo de Biogeoquímica Marina, Instituto de Investigaciones Marinas
(IIM-CSIC).
C/ Eduardo Cabello 6, 36208
Vigo (Pontevedra), Spain.
Tlf: +34986231930
e-mail: pbernard@iim.csic.es

Vigo, February 2010

Dear Dr. Roger Harris,

You can find attached the second revision manuscript entitled ***'Biocoenosis and thanatocoenosis of diatoms in a Western Galician Ría'*** to be considered for publication.

We gratefully acknowledge the constructive and valuable comments of the referee on the statistical approach.

Please could you acknowledge upon receipt of the manuscript. In case of any doubt, do not hesitate to contact me.

Yours sincerely,

Patricia Bernárdez Rodríguez

The authors

Manuscript ID JPR-2009-202.R1 entitled "Biocoenosis and thanatocoenosis of diatoms in a Western Galician Ría" which you submitted to the Journal of Plankton Research, has been reviewed. The comments of the reviewer are included at the bottom of this letter.

You will see that the reviewer expresses serious concerns about the statistical approach (R-mode analysis) that remain unresolved even after revision. In the reviewer's opinion, this manuscript should only be published if this problem is resolved.

The Associate Editor, upon the advice of an independent biostatistican, notes that the expectation of > 80% variance explained in multivariate ordinations is perhaps too stringent. However, overall, the points made by the reviewer are valid. The reviewer's concerns about the robustness of the results might be addressed by bootstrapping or other randomisation methods.

The Associate Editor recommends that the authors justify their approach through a further revision. Perhaps the combined analysis of both environmental and abundance information in a single PCA is not necessarily the best approach and may in some respects have caused the concern on the part of the reviewer. Canonical correlation analysis, or two separate PCA's or ANOSIM or MANTEL or PCA with multiple regression type approaches may have been more appropriate methods for the purposes of this paper.

As suggested by the referee statistical analysis was improved.

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Numbering of headings were deleted from the manuscript.

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Once again, thank you for submitting your manuscript to the Journal of Plankton Research and I look forward to receiving your revision, once you have completed it.

Yours sincerely,

Dr Roger Harris

Editor in Chief, Journal of Plankton Research

RPH@pml.ac.uk

Reviewer(s)' Comments to Author:

Reviewer: 1

Comments to the Author

Overall the authors addressed the reviewer's comments and suggestions and made the necessary changes. They also included more maps and explored into more detail some ecological aspects (such the relationship between freshwater diatoms and salinity) that enriched the manuscript.

However there is still one problem with this manuscript: the statistical approach is still confuse and weak. The arguments that the authors used for their statistical analysis (both in the manuscript and in the replies to the reviewer's comments) are not credible neither supported by any previous published book or paper references. The final result of the R-mode analysis (54.6%) is only sufficient to explain half of the processes affecting sedimentation in this area. By reading the authors' statistical approach, I have more questions than answers. My attention goes to the remaining sedimentation processes since these are the ones that, although as important (in terms of percentage of variance) as the marine primary production vs land factors (or PC), are ignored. The 2 factors accepted here have the highest loadings in the Inner Ria therefore more factors are needed to separate the oceanic processes into more detail and the term "marine primary production" does not fully apply to factor 2.The 3rd factor that the authors did not accepted actually is important from a statistical point of view and would give the marine primary productivity much better support (although the loading values for a 3rd factor are lower, that is just because these values decrease as the % of the variance explained by a factor is less).

> As suggested by the referee statistical analysis was improved. A new R-mode factorial analysis was carried out. Other analyzed variables were included. As suggested by the referee we have extracted several factors (those with eigenvalues higher than 1) in order to explain better database.

Also, another issue that at this point prevents my agreement to publish this manuscript is that in the previous review I suggested that the type of sediment should be included in the R-mode analysis. The authors state in their reply that "We do not have data regarding type of sediment (page 6)". However, Table 1 (Sediment characterization at the sampling sites) shows the mud content (%). In addition, the authors also point to sample S9 problem, where this sample "does not load in both factors since it has high sand content (page 6), reflected by its low mud content (table 1). This is inconsistent. The authors not only have the data but also use it to understand why the R-mode analysis with only 2 factors does not fully work for a particular sample. Why did the authors state that they do not have data regarding the type of sediment? And why do they not use it in the R-mode analysis (as they used TOC or TN, for example)?

> Sediment characterization was carried out by dry sieving, using <63 μm and <2000 μm sieves. In this way, we quantify the gravel, sand and mud fraction. However, from a sedimentological point of view, this grain size quantification is weak, since we must include more laboratory treatments of the sample and specific equipment (e.g. Coulter or X-ray diffraction using a Sdigraph) for the determination of the grain size. A

detailed grain size-distribution map of the ria can be found in Vilas et al. (2005). However, as suggested by the referee we include data on mud content obtained by dry sieving (% dry weight) in the database used for statistical analysis.

Therefore, since the R-mode only confirms what the authors observed with the mapping of the several variables (page 24), I only advice the publication of this manuscript if this statistical approach is removed from the paper and the discussion and conclusions will be re-written accordantly. In addition, maps of the geochemical parameters should be included.

Since statistical analysis was improved, maps of the geochemical parameters were not included.

Particular comments regarding the statistical approach:

1) The correlations are important. Therefore a table needs to be presented to the readers (not just to the reviewer). It is hard to follow section 4.4 without the table.

2) Correlations are not defined as "good", "close" or "high". Correlations' statistic significance is calculated depending on the number of degrees of freedom and the significance level chosen by the researcher. Therefore, the same table needs to show which correlations are significant at what level.

A new table (Table 3) including the Pearson correlation coefficients and the confidence levels at 99 and 95 was included (n=27). Corrections on the text were also done in the section 4.4.

3) In the comments to the reviewer, the authors state that they "only include significant variables" and that they "eliminated highly inter-correlated variables" (page 5). I am assuming that when the authors talk about significant variables they are referring to significant correlations (the authors do not explain what type of significance is being used). If this is the case, then the correlation table includes correlations that are not statistically significant. If this is not the case, then the authors need to define their concept of "significant variables" and explain their reasoning (in a statistical way) to choose certain variables. In addition, when the authors eliminated highly inter-correlated variables, they should have eliminated variables such as "phytoliths" which is statistically significant with other 7 variables (benthic, freshwater, TOC, TN, opal, valves and crysophycean). There are other variables that have similar problems and this affects the final R-mode results (as it was referred in the previous reviewer's comments).

We do not include variables highly inter-correlated, such as C/N ratio, since this variable is a result of the combination of the TOC and TN. In this new statistical approach we include all variables obtained, such as Radiolarians, Palinomorphs, Silicoflagellates, Rhizosolenia, Mud, *S. costatum.* and *Actiniscus pentasterias.*

4) R-mode analysis is a statistical method that "attempts to reveal a simple underlying structure that is presumed to exist within a set of multivariate observations" (in Davis, 2002 "Statistics and Data Analysis in Geology") which is different than using R-mode "to investigate the covariability between the different biosilicious components and geochemical parameters (page 18)". What would happen if a factor was only composed of diatom species variables and

no geochemical parameters or vice-versa? R-mode is not the best statistical approach to compare a certain type of variables with another type of variables and see if they covary.

"Communalities are equal to the original variance…if we extract fewer factors than original variables, the communalities will be less than the original variance, and provide an index to the efficiency of our reduced set of factors" (in Davis, 2002 "Statistics and Data Analysis in Geology"). There are publications where the authors do not accept analysis with communalities lower than 0.7 (e.g. Feldberg and Mix, 2002) because this means that only 70% of the variance in a variable is being explained by the factors that were kept. For example, Chaetoceros have a communality of 0.557. This means that only 55.7 % of this variable contribution for the overall variance of the dataset is being picked by the final 2 factors. The goal of any factor analysis is to reduce a dataset that has lots of variables (many times much more than the ones used in by the authors) to another dataset with fewer factors that have high communalities (higher than 0.7). This means that a huge dataset can be transformed in a small one as long as it preserves (or keeps the same percentage of variance, as close to 100% as possible) the variance (therefore the basis for R-mode analysis).

The final choice on how many factors one should keep must be done using several criteria. In addition, there are statistical procedures to help defining how many factors to keep: broken-stick and scree-plot are two methods. The authors preferred to keep only 2 factors. Instead of following the eigenvalue approach (one other method that states that one should keep all factors that have eigenvalues higher than one, in Davis, 2002) the authors justify their choice in a manner that does not have statistical meaning: the sedimentation graph (which the reader do not know where it is), and in order to simplify and explain adequately the results (who defines how simple and adequate the results of a particular analysis need to be presented to the reader). The terrestrial/marine influences are not the only processes affecting sedimentation distribution; therefore not showing the remaining factors (or at least their eigenvalues) is blocking the reader's access to the full statistical results. The authors can present all the factors that are statistically significant and assume that some factors are more easily explained than others (which is only natural and understandable as this type of data has a considerable amount of noise in it).

> We agree with the referee comments. In this way, we choose factors (six) with the eigenvalues higher than one.

Overall, most communalities in the authors analysis are low (lower than 0.7) therefore expressing the low % of variance explained (54.6%) by the 2 factors. Low communalities are a reflection of the presence of no-analogs (Feldberg and Mix, 2002). These no analogs are created because the two factors retained, by themselves, are not able to reproduce the variables' variance (the R-mode analysis is not reliable as there is about 50% of the variance in the original variables that was lost, that is, was not reproduced by the R-mode analysis). The 3rd factor explaining 10% is well accepted in factorial analysis (e.g. Pisias et al, 1997; Morey et al, 2005) and actually by looking at the *P. sulcata* an *L. danicus* distribution maps, it would be more indicative of marine primary productivity than PC2. PC2 has the highest loadings in the inner ria and they are not "confined (page25)" to open-ocean neither are the "factor scores highly positive in the oceanic domain (page 25)" and thus the term "Marine primary production" does not correctly expresses this factor. The low factor loadings that the authors

refer for a possible 3rd factor is in part a reflection of the fact that there are less samples from Open Ocean than from the ria and that the 3rd factor is explaining less variance.

We have obtained 6 factors using the extracting criteria as eigenvalues higher than 1. PC1, 2 and 3 each one explained more than 10% of the variance. Communalities obtained by the R-mode factorial analysis are higher than 0.7 reflecting the presence of analogs.

The interpretation of the factors extracted was rewritten and in section 5.2 and shown in figure 6. In this way, PC 1 was interpreted as 'land and freshwater influence', PC2 reflects mixed condition of terrestrial and oceanic processes and PC3 is indicative of the oceanic influence.

Communalities

	Initial	Extracted
Benthic	1.000	.794
Freshwater	1.000	.775
Thalassiosira spp.	1.000	.712
T. nitzschioides	1.000	.921
L. danicus	1.000	.581
P. sulcata	1.000	.848
Chaetoceros R.S.	1.000	.657
S. costatum	1.000	.877
TOC	1.000	.872
TN	1.000	.934
Opal	1.000	.808
$CaCO_3$	1.000	.779
Diatom valves	1.000	.882
Crysophycean cysts	1.000	.907
Palinomorphs	1.000	.770
Porifera	1.000	.823
Silicoflagellates	1.000	.882
Phytoliths	1.000	.904
Rhizosolenia spp.	1.000	.600
Radiolarians	1.000	.851
Mud	1.000	.791
Actinicus pentasterias	1.000	.791

Summarizing comment 4; as it is the R-mode analysis is not correctly done and induces the readers in error. The authors should either do it suitably (having in consideration the reviewer comments) or completely remove it from the manuscript and making the necessary text adjustments.

R-mode analysis was improved and the corrections on the manuscript were carried out.

5) The variables to include in any factor analysis cannot be "deciphered" before hand neither can be considered by previous R-mode analyses results: the ones that result in a "lower

percentage explained" (page 6 reply to reviewer comment #6) have a certain statistical meaning. By choosing groups of variables to include in R-mode and then choosing the best results to define which variables to present in the manuscript, violates the basic assumption of R-mode statistics and therefore, the authors are biasing their statistical analysis towards the final result that helps to proof their theory. The number of variables to include in factor analysis is not restrictive as this type of analysis does not limit this aspect, therefore the maximum number of variables of interest should be included.

> In order to avoid the biasing of the statistical analyses, all variables of interest (see comments below) were included in the R-mode factorial analysis.

6) In page 14 the authors define "main diatom species in the sediments" as the ones that have "3% frequency in at least one sample". However, fig. 4 shows a map of the abundance of the main diatom species for Rhizosolenia spp. That has less than 3% (the maximum value in the color bar is 1.2%). Is this a particular interesting species that was considerate? If so why and why was not included in the R-mode analysis.

> Although Rhizosolenia has a small contribution to the diatom abundance in surface sediment, this species was now included in the statistical analysis. We include the map of abundance of this species since their contribution in the water column is high, however, it practically disappears from the surface sediment.
>
> Changes in the text were done in section 3.2.

7) In page 17 (section 4.3) the authors give the abundance values for several species (mean, range) but not for Skeletonema and Rhizosolenia. The authors should be consistent and add percentages to these species too.

> Abundance values of Rhizosolenia and *S. costatum* in the surface sediment were included in section 4.3.

8) The removal of the percentages of opal contributors in page 18 left remaining of its presence in a couple of sentences. When the authors write "Phytoliths followed by cingulim and cysts are other important contributors" implies that they are in a certain order of importance. This was inherited from the previous version of the manuscript and the authors only removed the percentages values. The authors should also rewrite this part in a manner that no "associated "importance is given to the opal "contributors".

> Several phrases were rewritten or deleted from the manuscript.

9) Type in line 40-41 page 18 (implies and? aeolian).

> Changes in the text were done.

10) In page 20, lines 14-17: first the authors state that Chaetoceros vegetative cells abundance is high in traps (and water column). Then, in the following sentence they state that these species are rarely found in the traps (and sediments). If this is not a contradictory statement, why are Chaetoceros vegetative cell abundant in traps in this study case?

We agree with the referee. High abundances of vegetative cells of *Chaetoceros* were found in the water column, but not in the traps (Figure 3). In this way, phrase was rewritten as follows 'While *Chaetoceros* abundance of vegetative cells is high in the water column, it decreases in the traps and surface sediments (Fig. 7).'

11) The authors state that they do not have data regarding the type of sediment. If this is correct, then a reference is missing in lines 28-32, page 23 "Grain-size variations along the ria suggest that the lower diatom abundances…". I believe that the reference missing must be Vilas et al (2005). Otherwise the readers are lead to believe that the authors also did the grain-size analysis and therefore would have data regarding the type of sediment.

We have data on gravel, sand and mud content of the sediments, obtained by dry sieving. However, a detailed description of the types of sediment and grain-size variations along the ría can be found in Vilas et al. (2005).

12) In page 25, lines 33-35 the way the sentence is written it seems that benthics are also related to high productivity (as *P. sulcata*) because it is written "their (*P. sulcata* and benthic from the previous sentence) appearance in surface sediments is related to high productivity and upwelling development."

Phrase was changed as follows 'In the outer areas of the ria, *P. sulcata* appearance in surface sediments is related to high productivity and upwelling development.'

13) Why is the oceanic influence (PC2) referred as "Marine primary production"? The land influence (PC1) also induces high primary production (although with different species), and it was named "land and freshwater influence factor" (if line 61 page 24) or "land influence" (if fig.6). Should not PC2 be referred as "ocean and upwelling influence factor" or simply ocean influence. The authors definition for PC2 only makes sense if the oceanic influence is always related to high primary production (or at least higher than in the ria). Other question is if indeed PC2 is reflecting primary production and seeing that the highest sample loadings are in the inner ria (fig. 9, east of sample g12) should not PC2 be named "high primary production factor" (regardless of oceanic or land and fresh water influence)? The authors should also keep in mind that PC2 has opal as a major contributor and that not all opal is primary producer (e.g. diatoms) originated.

Figure 6 was restructured showing the factor scores and the percentage of the variance explained by the factorial analysis. Figure 9 showing the factor scores of the principal components was deleted from the manuscript. The interpretation of the factors extracted was rewritten in section 5.2.

14) In figures 3 and 4, the graphs for inner ria vertical flux are missing the dot connecting line for the last dot.

Figures were corrected.

Biocoenosis and thanatocoenosis of diatoms in a Western Galician Ría

Patricia Bernárdez[1,2,*], Manuel Varela[3], Yolanda Pazos[4], Ricardo Prego[1], Guillermo Francés[2]

[1]Grupo de Biogeoquímica Marina, Instituto de Investigaciones Marinas (IIM-CSIC).C/ Eduardo Cabello 6, 36208 Vigo, Spain

[2]Departamento de Geociencias Marinas y Ordenación del Territorio, Facultad de Ciencias del Mar, Campus Lagoas-Marcosende s/n. Universidad de Vigo, 36310, Vigo, Spain

[3]Instituto Español de Oceanografía (IEO), Centro Costero de A Coruña. Paseo Marítimo Alcalde Francisco Vázquez 10, 15001 A Coruña, Spain

[4]INTECMAR, Peirao de Vilaxoán, 36611 Vilagarcía de Arousa, Spain

*Corresponding author. E-mail: pbernard@iim.csic.es

Tel: +34986231930

Fax: +34986292762

Abstract. Seasonal variability of diatom abundances was measured in the water column, sediment traps and in the underlying sediment from the Pontevedra Ría. Seasonal variations of the diatom species in the water column were indicative of ocean influence, river influx and water column stratification. Additionally, analysis of diatom distribution and other biosiliceous components was studied in 27 surface sediment samples. The marine planktonic assemblage in the surface sediments is located in the outer area of the ría. It is mainly composed by *Chaetoceros* resting spores (R.S.) together with *Thalassionema nitzschioides*, *Leptocylindrus danicus* R.S. and *Paralia sulcata*. Higher abundances of freshwater assemblages are limited to the inner ría, as well as crysophycean cysts and phytoliths, where the Lérez River has its strongest influence. Benthic group is also restricted to the innermost and shallow areas where low water depths allow for growth. Factor Analysis distinguished between estuarine-freshwater and ocean-dominated upwelling areas in the Pontevedra Ría. A mixed area where both processes take place was also discriminated. A good agreement between the biocoenotic and the thanatocoenotic diatom community was found. Spite the low preservation of some species obscures the interpretation of the sedimentary record biogenic silica flux and accumulation reveal useful in the reconstruction of hydrodynamics and production in the marine paleo-records in Ría and estuarine domains, even though the low preservation of some species results in difficulties interpreting the sedimentary record. Biological response, production patterns and diatom succession related with their ecological preferences in this ría can also be applied to other rías and temperate coastal environments.

Keywords: diatoms, water column, sediment, sediment traps, Rías Baixas, NW Iberian Peninsula, Spain, *Leptocylindrus danicus* resting spores, *Chaetoceros* spp. resting spores, *Thalassionema nitzschioides*, *Paralia sulcata*

INTRODUCTION

The upwelling-influenced continental margins and coastal ocean are known to be among the most productive biological systems in the ocean, accounting for a high percentage of the primary productivity in the marine environment (Walsh 1991). One of these areas is the Galician coast. The high primary productivity of the Galician small embayments known as Rías is attributed to nutrient enrichment from coastal upwelling which favours phytoplankton growth. Studies on phytoplankton succession in the Galician Rías (Margalef et al. 1955; Figueiras and Niell 1987; Varela 1992; Varela et al. 2004; Varela et al. 2005) describe a predominance of diatoms due to upwelling influence. However, their contribution to phytoplankton dynamics and impacts on regional biogeochemistry are poorly understood yet. Although there is a large body of knowledge of phytoplankton ecology in the Rías, little information exists about the dynamics and ecological characteristics of the particle fluxes and export of the biogenic material from the water column to the sediment. Moreover, very little is known in the Galician rías and continental shelf about the diatom abundance and biogenic silica distribution patterns in the sediment reflecting present day hydrography and productivity conditions (Margalef 1958; Bao et al. 1989; Bao 1991; Bao et al. 1997; Prego and Bao 1997; Bernárdez et al. 2005; Bernárdez et al. 2006; Bernárdez et al. 2008). These studies addressed to quantify the record of the biosiliceous material and its relationship with the pelagic downward fluxes has not been conducted in a Galician ría yet. In this way, there is a need of connecting all the information about the composition and structure of the pelagic community, their vertical flux to the seabed and their record in the sediment.

In this paper, quantitative analyses of the diatom composition were carried out on samples from the water column and sediment traps of a western Galician ría to assess the seasonal and spatial variability of this biosiliceous material and fluxes to the bottom. We study the silica stock in the water column, biosilica downward fluxes, and opal accumulation on the seafloor, in order to ascertain the preservation biases of the assemblages during settling and within the sediments. The comparison among the three environments highlighted the abundance of the siliceous components in the superficial sediment and its relation with the hydrography.

The specific objectives of this paper are as follows: (1) to compare the diatom content in the traps and water column with those preserved in the surface sediments and attempt to extrapolate results for paleoceanographical and paleoproductivity interpretations (2) To compile the extent and limitations of fossil diatom distribution in surface sediments as tracers of hydrography and oceanography focusing on the interpretation of these organisms as paleoclimatic tracers down-core. To our knowledge, this is the first study carried out in a ría integrating the information of the diatom

composition in the water column, sediment traps and the biosiliceous elements in the surface sediment.

REGIONAL SETTING

The Galician rías (NW Iberian Peninsula) are a set of estuary-type coasts best described as drowned river valleys formed by sea flooding during Pleistocene-Holocene transgression (Vilas 2002). The Pontevedra Ría, belonging to the group of Rías Baixas, is oriented in a SW–NE direction and widens progressively from the Tambo Island toward the mouth (Fig. 1). Ría exhibits different characteristics according the degree of estuarine-marine influence, hydrodynamic and sedimentologic characteristics, and can be divided in several sectors. The outer zone presents mostly a sandy cover, with high abundance of coarse carbonate–rich sediments (Vilas et al. 2005) (Fig. 1). The inner part can be considered as an estuary from both hydrographic and their resulting sedimentological considerations, with the main estuarine processes being confined to the inner relatively small brackish water zone (Evans and Prego 2003). This zone is characterized by the presence of fine–grained and organic–rich sediments (Vilas et al. 2005).

At the ría head Lérez River provides the main freshwater runoff which flows into the estuary, depending on the rainfall pattern (Prego et al. 2001; deCastro et al. 2006a). Ría acts as a partially mixed estuary with a double-layered residual pattern (Prego et al. 2001; Gómez-Gesteira et al. 2001; Ruiz-Villarreal et al. 2002; Álvarez et al. 2003; Gómez-Gesteira et al. 2003; deCastro et al. 2004). Circulation within the ría is driven by the entrance of oceanic water masses when northerly winds are persistent forcing an offshore Ekman transport in the upper layer, and upwelling occurs in spring and summer (Fraga 1981), together with the freshwater input at the head of the ría during rainy periods, tidal forcing and the wind regime which is mainly SW or NE (Gómez-Gesteira et al. 2001).

Nutrient fluxes into the Pontevedra Ría were strongly driven by the incoming oceanic flow throughout the year (Dale and Prego 2005), exhibiting a pronounced seasonal variation. In late spring and summer, upwelling favourable winds are usual, and *Eastern North Atlantic Central Water* (ENACW) is upwelled into the ría (Fig. 1), renewing nutrients (Tenore et al. 1982). At other times of the year terrestrial runoff is the dominant nutrient supply. Phytoplankton blooms in the Rías Baixas occur in spring (mainly of large diatoms) and autumn (mixed populations of diatoms and dinoflagellates) (Figueiras and Niell 1987; Varela et al. 2008). However, the highest phytoplankton biomass is usually observed during summer due to the effect of upwelling (Campos and Mariño 1984; Figueiras and Niell 1987; Varela et al. 2001; Varela et al. 2004). Most of the

phytoplankton growth inside the rías is induced by regenerated nutrients from organic matter in shelf waters that are re-entered in the rías when upwelling occurs (Fraga 1981; Prego 1994; Álvarez-Salgado et al. 2000). Primary production in the Pontevedra Ría varies considerably depending on the balanced influence of upwelling and runoff. It is characterized by the export to the sediment of large quantities of organic carbon and organic materials (Varela et al. 2004).
Therefore, the Pontevedra Ría constitutes an interesting area of study due to the following reasons: i) the Ria, like most of the estuaries in the western coast of the Iberian Peninsula, is under the effect of strong upwelling/downwelling episodes, which reinforce or stop the estuarine positive circulation and the primary productivity, ii) Seasonal changes in productivity are closely related to changes in hydrography, iii) The river flowing at the head leads to a large mixing zone between the continental and oceanic waters.

MATERIAL AND METHODS

Sampling

Water column sampling was carried out fortnightly on board the R/V 'Mytilus' between February and June 1998, covering the most important oceanographic periods; winter mixing, winter upwelling events, spring bloom and upwelling (Álvarez et al., 2003; Varela et al. 2004; Prego et al., 2007). Seawater samples for diatom cell counts were collected at Stations O, M and I with Niskin 'General Oceanic' bottles at discrete depths of 0, 5, 10, 20, 30 and 50 m (depth permitting and 5 m above the seafloor) (Fig. 1).
Water column particulate material was collected with a multitrap collector system (Knauer et al. 1979) deployed 5 m above the sea bottom and anchored to the seafloor at the same water column stations (O, M, I) for periods of ~24 h (Fig. 1).
For the determination of the biosiliceous material abundance in the sediment, fieldwork consists of a sediment sampling cruise in April 1997 covering all the ría. 27 surface sediment samples were collected using a Shipek grab (Fig. 1).
Upwelling index was calculated by means of the geostrophic wind speed obtained from atmospheric pressure Welds at grid reference 43°N 11°W (Lavín et al. 1991), using the methods described by (Bakun 1973). The discharge of the Lérez River was measured daily at a gauging station located at the boundary of the limit of tidal influence (Prego et al. 2001) (Fig. 1d)..

Procedures and analytical strategies

Diatom identification and cell counting of the material collected in the traps and in the water column were performed in samples preserved with Lugol's solution to be examined under a inverted microscope following the technique described by Utermöhl (1958). Organisms were identified and counted using a magnification of 40×, 100× and 250× and 1000×. The nomenclature and taxonomic identification for species followed that of Tomas (1997). Results are expressed as diatoms m^{-2} day^{-1} for the sediment traps and cells (diatoms) l^{-1} for water column. Results are also expressed as relative abundance of each species averaging the complete sampling period.

The procedure for the treatment of raw material for biosiliceous counts follows the method devised by Abrantes et al. (2005). A microscope with phase contrast optics and a magnification of up to 1000× was used for diatom quantification and identification. Several non-overlapping transverses covering both central and marginal zones of the cover slip were examined depending on the diatom abundance. At least 300 diatom valves were identified, when possible, to the lowest taxonomic level in each sample, to ensure proper assessment of diatom composition. Raw counts were then converted to percent abundance. Taxonomic identification and grouping is based on ecological characteristics as stated in well-known bibliographies and was made using several floras (Hustedt 1930; Hustedt 1959; Round et al. 1990; Hartley 1996; Hasle and Syvertsen 1996; Witkowski et al. 2000). Schrader and Gersonde's (1978) recommendations were followed for diatom counts and total number estimates, so only diatoms that were essentially whole were counted.

Taxa were gathered into three different types: dominant taxa, species of the same genus and species showing comparable ecology and distribution e.g. freshwater and benthic (Taxonomic appendix). Number of *Actiniscus pentasterias*, silicoflagellates, sponge spicules, palynomorphs, phytoliths and crysophycean cysts per gram of sediment was also assessed.

Siliceous microfossils and components distribution were plotted using the Golden Software Surfer 8.0 package for Windows, using the Kriging method for data interpolation.

Geochemical data of the superficial sediment were supplied by project MAR96-1782. Experimental procedures were obtained from the paper published by Dale and Prego (2002). Data included the content of total nitrogen (TN), total organic carbon (TOC), total inorganic carbon (TIC), calcium carbonate, and opal (biogenic silica or BSi) (Table 1).

R-mode factor analysis (Principal components is the factor extraction) was carried out using the software package SPSS 13.0.1 (LEAD Technologies) for Windows, using as variables the relative abundance of the diatom species in sediments, the concentration of the geochemical parameters (TN, TOC, opal and $CaCO_3$) and the absolute abundance (# g^{-1}) of biosiliceous compounds (phytoliths, crysophycean cysts, porifera, *A. pentasterias*, radiolarians, silicoflagellates and diatom

valves), palinomorphs and mud content of the sediment. Variables were standardized to mean zero and standard deviation one for each species and variables, having a similar weight, permitting the comparison of their variance.

RESULTS

Diatom assemblages in the water column

Diatoms showed a high seasonal variability (Fig. 2). High diatom abundance is recorded on February 25th, May 12th and June 23rd. Periods of moderate diatom abundances included February 11th, March 3rd and 24th and April 27th sampling dates. On average, diatom abundance varies between 4.8×10^6 cells l^{-1} for the outer station, 4.7×10^6 for the middle and 10.5×10^6 in the inner one. *Chaetoceros* spp. are the dominant taxa accounting around 60–70% of the assemblage in the area. Low abundances were found on February 24th, March 11th and June 10th for the outermost stations and also on February 11th and June at the innermost station. The contribution of the *Chaetoceros* resting spores (R.S.) in the water column was very low at all stations, excluding June 23rd and February 25th.

Leptocylindrus danicus peaked on June, ranging from 20 to 83% in all sites and on May 26th at the outer station. This species represents an important contribution to the assemblage during low diatom production periods and at all stations, reaching the 50% of their abundance in the outer station.

Thalassionema nitzschioides showed a low relative abundance over the complete period, excepting during April at the stations O and M, when a significant percentage, varying from 3 to 16% was found. However, high absolute abundances were found in 27th April and 12th May. At the sampling site I, relative high percentages were found at February 11th (6.3%) and April 13th (4.6%).

Skeletonema costatum peaked on May 12th at all stations, and also on February 11th at the stations M and I. This species constitutes a high fraction of the total assemblage only during elevated diatom production on May 12th ranging from 15.5 to 25.4%, being almost absent the rest of the period studied.

Rhizosolenia spp. only appeared in the outermost stations (O, M) during the February 11th sampling date (18–22%). On June 6th it represented a relative high percentage (around 7-8%) in all sampling sites.

Thalassiosira spp. did not show high abundances. Relative percentage is about 4–8% on February 11th and especially, on May 12th. This group presented lower absolute abundances in the water column at the innermost sampling site in comparison with the stations O and M.

Freshwater diatoms, the benthic assemblage and the tycoplanktonic species, *P. sulcata*, appeared in winter, in February, and also during April 13th, coinciding with periods of high runoff, sediment re-suspension and high turbidity.

Diatom assemblages in the sediment traps

Diatoms downward fluxes were highly variable during the whole sampling period (Fig. 3), showing a prominent peak on February 25th (2600–5700 cells m^{-2} day^{-1}) and high values on May 12th (1100–1800 cells m^{-2} day^{-1}) and on June 23rd (2000–3800 cells $m^{-2}day^{-1}$). The main flux events found are due to the high proliferation of *Chaetoceros* spp., on February 25th, March 11th and June 23rd. Low fluxes were measured during early February and in April. Daily flux of these species is high during high production in the water column, accounting ~80% of the assemblage. The main contributor of the *Chaetoceros* spp. to the sediment traps are their resting spores, representing up to the 97% of the total diatom concentration. Very low diatom sedimentation rates were recorded on 10th June coinciding with the disappearance of this group in the traps and the prevalence of other species.

Leptocylindrus danicus exhibits two peaks on March 24th and May 26th at the outermost station and one peak on May 26th at the station M. *L. danicus* was almost absent at the innermost station, excepting on March 11th. In general the contribution of this species is higher during periods of low diatom production.

Thalassionema nitzschioides downward fluxes peaked on April 27th in all stations, accounting between the 33 and 73% of the assemblage and also on February 11th at the station I. Its vertical flux is roughly constant through time.

Skeletonema costatum contributed in a significant portion, but only during short periods of time e.g. May. In the innermost station its contribution was almost negligible, increasing at the outermost stations.

Maximum concentrations of *Rhizosolenia* spp. occurred on June, accounting up to 33% at the inner station and around 8% at middle station. Its contribution was also important on February 11th at the station O.

Thalassiosira spp. daily fluxes were very low in comparison with other species and groups. Seasonal pattern showed strong variations in abundance and flux. In the outer and middle stations their relative abundance was significantly higher during low/moderate diatom production periods, in April and February 11th. Higher contribution of this species was found at the station I during May.

Paralia sulcata appeared occasionally in the sediment traps, especially on April, even though its relative abundance can reach values of 14%.

Benthic group was poorly represented in the sediment traps, however higher values (up to 10%) were observed during low production periods in winter. Freshwater assemblage showed two distinctive peaks on June 10th at the outermost station and on April 27th at the sampling site I. As observed for the benthic taxa, its contribution to the total assemblage as well as downward fluxes is very low.

Diatom assemblages and biosiliceous components in the surface sediment

The distribution pattern of diatom abundance (Fig. 4) is characterized by the elevated values in the middle an in the northern coast of the inner ría. The outer ría is poor in diatoms, with absolute abundances between 6.8×10^5 and 2.4×10^5 valves g^{-1}. Moreover, lowest diatom concentrations were found at the stations located at the ría mouths. Diatom absolute abundances in surface sediments ranged between 1.98×10^5 (station 14) and 24.3×10^5 (station S4) valves g^{-1} with a median value of 10×10^5 (Table 2).

Diatom community is mainly composed by *Chaetoceros* resting spores (R.S.) ranging from 13% (station N1) to 86% (station N5). Among the several types of *Chaetoceros* R.S. four stand out as the main contributors in the sediment: R.S. *C. affinis*, *C. diadema,* and *C. compressus*. Vegetative frustules of *Chaetoceros* spp. were scarce in the sediment. Highest percentages were located in the middle-outer areas of the ría and low values were found at the innermost sampling stations (Fig. 4).

Paralia sulcata is the second main component of the assemblage (Fig. 4) (0–20%) and presents a scattered distribution pattern throughout the ría. Higher abundances were found especially in the external ría and also along the longitudinal axis, whereas this species is absent at the stations located close to the Lérez River mouth.

The third species in importance is *T. nitzschioides* (Fig. 4). Relative abundance was within the 2.3–10% range. Distribution was similar to that found for *Chaetoceros* R.S. Maximum percentages were located in the outermost stations, but also, relatively high concentrations are found in the innermost ría at the southern margin.

Leptocylindrus danicus R.S. have a mean value of 3.2 % with maximum abundances at the station 15 (17.8%). Its distribution is roughly uniform throughout the ría, excepting that station with the maximum percentages. It is almost disappeared at the innermost area and at the northern margin of the external ría (Fig. 4).

Thalassiosira spp. was found in very low abundances (0–3.3%), with a heterogeneous distribution throughout the ría. Higher concentrations were found at the inner ría and in the northern shore (Fig. 4).

Skeletonema costatum as well as *Rhizosolenia* spp. were very scarce in the surface sediment (<3%). In general, *S. costatum* was found in the southern margin of the inner ría with values up to 2.4% and *Rhizosolenia* spp. at the northern mouth in the external stations (~1%) (Fig. 4).

The contribution of benthic taxa is important in the shallowest stations of the inner ría (20–62%) with poor occurrences at the external part (Fig. 5). Pattern distribution of these taxa mirrors that found for the freshwater flora with the exception of the freshwater peak off Couso Point. The shift from the planktonic–diatom taxa dominance to the freshwater–benthic diatom assemblage is located at the station 12 (Fig. 5). Freshwater assemblage is restricted to the stations close to the ría head, at the Lérez River mouth, and especially in the northern coast (~10%), decreasing the relative abundance offshore (~6%). High percent abundance of this taxa is also found in the station 16 located in the outer ría (Fig. 5).

Although diatoms valves and fragments were dominant in sediments, silicoflagellates, radiolarians, crysophycean cysts, porifera, phytoliths and the siliceous dinoflagellate *Actiniscus pentasterias* were other important and useful constituents of the siliceous biogenic particles found in the sediments (Table 2).

Porifera concentration is high varying from 1.4×10^6 to 1.2×10^4 specimens g^{-1}, with higher values in the middle zone and at the southern mouth (Table 2).

Phytoliths, cingulum (diatom girdle bands) and crysophycean cysts (Fig. 5) are other contributors to the biosiliceous assemblage in the surface sediments. Highest phytoliths concentration was located at the innermost sampling stations from the northern coast. Crysophycean cysts were recorded in higher abundances at the inner ría, (1.4×10^5 to 1.6×10^4) resembling the pattern distribution found for phytoliths (Fig. 5). Since both parameters are of continental origin, their presence in marine sediments implies an aeolian or fluvial transport to the oceanic domain.

Silicoflagellates were present in low abundances, ranging from 0 to 2×10^4 specimens g^{-1}. Higher values were located in the inner-middle ría and they were not present in the longitudinal axis at the outer ría. *A. pentasterias* only appeared in the inner part of the ría and also in three stations located at the mouths. Radiolarians content was also very low, appearing in the northern margin of the ría and in the outer zone. Pollen forms were scarce all over the ría, however, they were present at the ría mouth, but the highest abundances about (2×10^4–4×10^4 specimens g^{-1}) were found in the innermost area (Table 2).

Relationships between geochemistry and biosiliceous components in sediments

Statistical methods (R-mode factor analysis) were carried out to reveal a simple underlying structure that is presumed to exist within a set of multivariate observations (Davis, 2002). In this

way we include in the database for statistical analysis biosiliceous components (including diatoms), geochemical parameters and the mud content of the sediments.

A high correlation was found between the benthic and freshwater assemblages with the terrestrial input indicators (crysophycean cysts and phytoliths) (Table 3). Also these variables have a positive linear correlation with the total organic carbon (TOC) and nitrogen (TN) content and negative with the carbonate content (Table 3). TOC/TN ratio in the sediment is also considered as a proxy of organic matter origin, and as shown by Dale and Prego (2002) higher values were found in the inner ría indicating continental supply. Opal content has a good correlation (99% of significance level) with *P. sulcata*, porifera, *A. pentasterias* and phytoliths. However, diatom valves abundance is well correlated with the TOC, TN and crysophytes. *Chaetoceros* R.S. has a significative positive correlation with *T. nitzschioides* and highly negative with the freshwater and benthic assemblage. *L. danicus* correlates well with *P. sulcata*.

R-mode factor analysis returned two principal component factors, which explained 80.71% of the variance of the dataset (Fig, 6). The PC1 (contribution to the total variance is 31.41%) loading positively mostly of benthic and freshwater assemblages, crysophycean cysts, phytoliths, TOC and TN concentrations, and negatively, with carbonate content (Fig. 6). The second component PC2 explained the 18.79% of the variance. Opal is the first scorer of this factor and *A. pentasterias* the second in importance, with a smaller contribution of *Chaetoceros* R.S. and *T. nitzschioides* species, porifera and silicoflagellates (Fig. 6). PC 3 explained 11.60% of the total variance, loading positively on *P. sulcata* and *L. danicus* and negatively on diatom valves abundance. PC4, PC5 and PC6 explained 7.09%, 6.50% and 5.32% of the total variance respectively (Fig. 6). These three principal components load on low preservation efficiency species such as *Thalassiosira, S. costatum, Rhizosolenia* and radiolarians.

DISCUSSION

Extents and limitations of diatoms as paleotracers

Mean relative abundances of dominant diatom species in the water column and in the sediment traps were compared to the relative contribution of each species and groups in the underlying surface sediments (Fig. 7).

Peaks in *Chaetoceros* abundance was due to different upwelling events (Prego et al. 2001; Varela et al. 2008) combined with high input of nutrients due to river runoff (deCastro et al. 2000; Álvarez et al. 2006; Varela et al., 2008). However, lack of northerly winds driving upwelling in June (Prego et

al. 2001) leads to a low abundance of this species and the proliferation of other taxa. *Chaetoceros* spp. have a high preference for conditions of high productivity (Abrantes and Sancetta 1985; Abrantes 1988; Pitcher 1990; Sautter and Sancetta 1992; Abrantes and Moita 1999; Romero et al. 1999; Abrantes et al. 2002). Since this species is the dominant component of the assemblage in the water column and sediment traps during high production periods and also in the sediments (Figs. 2 and 3) we conclude that this BSi reflects the high production conditions in the surface waters, usually due to upwelling (Bao et al. 1997). *Chaetoceros* R.S. dominance reflects the importance of the high primary production associated with fertilization by nutrients (Varela et al., 2008) when stratification is broken by upwelled waters. In fact, Rodríguez et al. (2003) found the highest abundance of diatoms between May and October during 1999 at a fixed station of the outer ría, and the most abundant species was *C. socialis*.

While *Chaetoceros* abundance of vegetative cells is high in the water column, it decreases in the traps and surface sediments (Fig. 7). These species are rarely found in the traps and sediments in the form of vegetative cells (Bao et al. 2000). However, with nutrient deficient and stressful conditions in the euphotic zone after the upwelling, they form resting spores very resistant to dissolution (Margalef 1978; Rines and Hargraves 1988; Pitcher 1990) becoming a major component of both the trap and the surface sediment assemblage (Blasco et al. 1981; Koning et al. 2001).

Thalassiosira group shows a progressive decay of their contribution from the surface waters to the sediment excepting in the innermost station (Fig. 7). *Thalassiosira* spp. proliferates on winter throughout the Portugal coast reflecting more persistent fertility conditions and continuous nutrient input (Abrantes and Moita 1999) decreasing their abundance when fertilization by upwelling occurs and *Chaetoceros* spp. dominate. *Thalassiosira* spp. distribution in sediments is indicative of their resistance and adaptation to conditions of relatively low nutrients input but constant in time, supplying by for example by the Lérez River. In this way, relative abundance is high in the northern margin due to northward displacement of the surface river waters due to the Coriolis effect (deCastro et al. 2006b). However, burial efficiencies for *Thalassiosira* spp. group are very low since it is present in very low percentages in sediments.

Dissolution of *Rhizosolenia* spp. occurs at the sediment-water interface before being buried (Fig. 7), but strong dissolution processes in the water column and within the sediment can not be discarded. The presence in the sediment reflects high preservation conditions under a suboxic-anoxic environment. Dissolution of siliceous valves of *Rhizosolenia* spp. within the sediments implies their limited use for paleoreconstructions. However, when found in high percentages are good markers of enhanced preservation conditions. As observed for *Thalassiosira* genera the high abundance in waters found in the innermost station is not reflected in the surface sediments. Higher percentages on February were related to the development of a winter upwelling bloom as also reported in

Saanich Inlet (Mcquoid and Hobson 1997). These cylindrical and slightly silicified taxa are related to a pre-upwelling bloom off Somalia by the end of winter and spring (Koning et al. 2001). Their dominance before the onset of the upwelling is due to their capacity to adjust their buoyancy, responding to changes in the thermocline and migrating vertically between the surface water and nutrient-rich deeper water and for nutrient assimilation (Villareal et al. 1999).

S. costatum can be found in higher percentages during short periods of time at the water column, but their abundance sharply decreases at the sediment trap, pointing to a strong dissolution within the water column due to the delicate structure of their frustules (Fig. 7). In this way, high concentrations of the high dissolution-sensitive species in surface sediments indicate high vertical fluxes of diatom valves to the seafloor and the effective preservation (Romero and Hebbeln 2003). This estuarine-adapted species appears in high abundances when upwelling conditions are relatively well developed and the input of nutrients is high, especially at the outermost stations. It is a good tracer of high productivity (Romero and Hebbeln 2003) and characterizes the spring bloom, for example in the British Columbia fjords (Sancetta 1989), but its low preservation efficiency hinder its use as a paleoenvironmental indicator. *S. costatum* is related to the input of nutrients by heavy rainfall run-off or constant river flow (Mcquoid and Hobson 1997; Nogueira et al. 2004). In this way, the appearance of this species in winter is linked to freshwater inputs and nutrients from the river flow (Casas et al. 1999; Varela et al. 2001; Varela et al., 2008). Although Rodríguez et al. (2003) found elevated percentages during a spring bloom at the end of May 1999 this species is one of the dominant during winter. In May 13th an important supply of continental freshwater was introduced in the shelf (Álvarez et al. 2006), reaching the Ría through the southern mouth leading to a typical early spring bloom that was linked to haline stratification (Varela et al. 2001; Varela and Prego 2003). This unusual patterns introduce high nutrients content suggesting the existence of a *S. costatum* bloom that penetrates the ría, embedded in a water mass that is fresher than the estuarine one (deCastro et al. 2006a). This fact is important for future paleoreconstructions, because this species, if preserved in high abundances and together with the amount of the freshwater assemblage, can be used as riverine input marker and inner estuarine processes.

Vegetative cells of *L. danicus* present a high relative contribution in the surface waters, but they completely disappear in the sediment traps (Fig. 7). It re-appears with high percentages, especially in the outer ría, with the form of resting spores. The non-appearance of this species in the traps in forms of vegetative cells is due to its delicate frustule or imprecisions during sampling in traps. The absence of spores in the traps can be the result of lack of sampling in the period just after the bloom of this species, when sporulation occurs. This species is a good indicator of last phase of upwelling when stratification occurs and nutrient levels drop (Casas et al. 1999; Varela et al. 2001; Bárcena et al. 2004). In fact, during the sampling period, *L. danicus* appeared in June6th, under water column

stratification conditions (Prego et al. 2001) and low nutrients content (Varela et al., 2008). It was also identified as a fast-growing competitor during late summer-blooms (Bode et al. 2005).

T. nitzschioides mean relative contribution progressively increases from the water column to the sediment for all stations (Fig. 7). This is due to the high preservation efficiency derived from to its strong frustule (Koning et al. 2001). Peak of *T. nitzschioides* in April in the water column and traps (Figs. 2 and 3) is related to the high riverine run-off (deCastro et al. 2000; Álvarez et al. 2006), the input of nutrients (Varela et al., 2008) and weaker upwelling conditions as shown by other authors (Pokras and Molfino 1986; Abrantes 1988). In this way, seasonal variation of their abundance is controlled by the input of nutrients when river runoff is high, coinciding with rainy conditions in winter (Margalef 1978; van Iperen et al. 1987; Abrantes and Moita 1999). However, this colony-forming species is also common in winter off Portugal coast around upwelling centres in less nutrient-rich waters, indicating periods of long but weakened upwelling (Abrantes 1988; Abrantes and Moita 1999), and in the Galician shelf, Bao et al. (1997) linked its appearance in sediments with weaker upwelling conditions and persistent nutrient input. This neritic species is indicative of low/weak upwelling production conditions (Bárcena and Abrantes 1998) and together with *Chaetoceros* R.S. could also help to track upwelling conditions with increased nutrient supply (Hasle and Mendiola 1967; Schuette and Schrader 1981a, b; Lange et al. 1998; Bao et al. 2000; Romero and Hebbeln 2003). Thus, *T. nitzschioides* tolerates variable conditions but the persistent presence of this species throughout the sampling period in the traps is also indicative of resistance even when nutrients content is low. *T. nitzschioides* is better able to get preserved in areas of low productivity/nutrient than other diatoms species, while with strong fertilization conditions it is diluted by fast-blooming species such as *Chaetoceros* spp. (Lopes et al. 2006). In our case, this species is indicative of high freshwater run-off and high rainfall and also tracks weaker upwelling conditions and constant nutrient supply.

P.sulcata is almost absent in the water column and sediment traps (Fig. 7). This tychoplanktonic diatom (McQuoid and Nordberg 2003) only appears during autumn and winter due to sediment resuspension caused by very intense vertical mixing in the water column (Margalef 1958; Sancetta and Calvert 1988; Casas et al. 1999). In the ría this mixing occurs when high freshwater input enters towards the embayment and higher current velocities re-suspend the sediments introducing allocthonous diatoms. In this way, high relative contribution of this species is detected during low diatom production periods under non-blooming events.

Benthic assemblage percentage is between 7 to 20 times higher in the surface sediments than in the water and traps (Fig. 7). Moreover, the appearance of these species (e.g. *Cocconeis* spp., *Diploneis* spp., *Navicula* spp.) in the sediment traps and water column, especially on April 13th (Figs. 2 and 3), is indicative of resuspension of the sediment typical in winter with high runoff (Figueiras and Niell

1987). In the Vigo and Ferrol Rías, benthic diatoms appears in very high percentage at all stations located in the inner areas (Bernárdez et al. 2006; Bernárdez et al. 2008). Their occurrence in the shelf or outer ría probably reflects littoral influence and transport from the innermost areas. Freshwater assemblage abundance in the water column and in the sediment is higher at the innermost station (Fig. 7) being indicative of the riverine plume with salinities around 30‰ (Prego et al. 2001). Therefore, freshwater group tracks the intensity and direction of the river plume.

Diatoms in surface sediments : paleoceanographic and paleohydrographic tracers

Estimated diatom abundances in the surface sediments of the ría (Fig. 4) fall within similar order of magnitude as reported for other coastal or shelf upwelling-influenced areas (Schuette and Schrader 1981a; Abrantes 1988; Lange et al. 1998; Romero et al. 1999; Nave et al. 2001; Romero and Hebbeln 2003; Hay et al. 2003). Values are in the range reported in nearby areas (Bao 1991; Prego et al. 1995; Bao et al. 1997; Prego and Bao 1997; Abrantes and Moita 1999). Lower diatom absolute valves abundance were recorded at the entrance channels of the ría (Fig. 4), where grain size is coarser (Vilas et al. 2005), reflecting a dilution effect through increased deposition of clastic material. Grain-size variations along the ría (Vilas et al., 2005) suggest that the lower abundance of diatoms in the outer areas could be a function of transport (diatoms being removed from coarser sediments) or preservation (with dissolution in more porous sediments). Favourable conditions for diatom preservation were usually reflected by high abundance estimates. Patterns of preservation were also related to the oxygenation conditions of the sediment. Oxic-suboxic conditions are commonly found at the inner ría, where mud content and organic carbon are high, leading to enhanced opal preservation. At the outer areas, coarser sediments permit the oxygenation of the sediment, favouring the fast dissolution of diatom frustules.

High abundances of *P. sulcata* in the outer sector point to an enhancement of this resistant diatom due to differential dissolution (Fig. 4). This species is also a tracer of high fertilization by nutrients and upwelling (Roelofs 1984; Abrantes 1988; Abrantes 1991; Bao et al. 1997; Bárcena and Abrantes 1998; McQuoid and Nordberg 2003 and references therein). Their appearance in high percentages at the outer ría can also reflect the oceanic influence and the entrance of high-nutrient shelf waters when upwelling is well developed. Due to resistance to dissolution, we must combine its employment as paleoproxy in *P. sulcata*-dominated biofacies for identificating high production areas with other biogeochemical markers (Bao et al. 1997).

The high productivity of the surface waters and the influence of coastal upwelling especially in the middle-outer areas of the ría are mirrored by the dominance of upwelling-related *Chaetoceros* R.S. (Fig. 4) as observed in the Vigo Ría (Prego et al. 1995). In contrast, *T. nitzschioides* geographical

distribution (Fig. 4) should be indicative of high riverine discharge and weaker upwelling conditions. However, its geographical distribution with lower percentages at the stations of the inner ría, do not resemble the distribution pattern of the freshwater assemblage (Figs. 4 and 5). This fact is due to the high contribution of benthic species in the inner parts of the ría, e.g. freshwater group. In this way, paleoreconstructions of freshwater influx using *T. nitzschioides* relative percentage in sediments as a tracer should be taking carefully in areas with a high input of allocthonous species. In the outer areas of the ría this species is associated to the constant nutrient supply from oceanic waters (Hay et al. 2003).

High percentages of *L. danicus* in the sediments of the outer ría are related to the lack of the benthic and freshwater assemblage and relatively low percentages of the *Chaetoceros* R.S. Moreover, *L. danicus* can be also indicative of areas where oceanic primary production is high.

Benthic taxa extent towards the inner ría in shallow areas, where light input depth-permitting. Their appearance at higher depths indicate transport from the inner areas, thus benthic taxa could be used in the paleoceanographic record as tracer of down-slope or down-shelf transport.

The freshwater assemblage showed a strong influence of the riverine plume at the innermost ría in the northern mouth, declining towards the middle ría (Fig. 8). Oceanographic surveys done at the same period also illustrated the extent of the low salinity river len and reduced freshwater retention (Prego et al. 2001), especially during high riverine discharge events, e.g. 13th April 1998 (Fig. 8). Moreover, other biosiliceous continental-derived material, as phytoliths and crysophycean cysts appears at the same stations and with the same distribution pattern of the freshwater assemblage (Fig. 5). Hay et al. (2003) also found the same features in a temperate fjord and other authors (Rebolledo et al. 2005; Lopes et al. 2006) on the Chilean Fjords and NE Pacific respectively.

In this way, mean annual surface salinity values were compared to freshwater percentages in the surface sediment in order to calibrate the use of this parameter as a marker of sea-surface salinity and indeed, high freshwater fluxes to the ria (Lopes and Mix, 2009). A correlation was obtained indicating that freshwater diatoms are good tracers of sea-surface salinity,

The appearance of high abundances of freshwater diatoms at a station located at the southern mouth of the ría could be related to the influence of the Miño River plume after extremes flood events (Fig. 8), as recorded during the sampling period in May (deCastro et al. 2006a). Lower salinities recorded at the southern mouth in the Vigo and Pontevedra rías are derived from the salinity plume located at the shelf and getting into the rías (Álvarez et al. 2006), and transporting allochthonous freshwater diatoms floating on the surface water.

Statistical analysis confirmed the idea of several areas in the ría, characterized by different oceanographic conditions. PC1 distribution is related to the innermost areas where estuarine processes dominates, reflecting the terrestrial input and riverine influence. In this way, we will

designate this factor as the 'land and freshwater influence'. The influence of the river plume is clearly identified in the sedimentary record. In coastal areas, an important contribution of land-derived material should be expected. Low values of the TOC/TN ratio (Table 1; Dale and Prego 2002), even in the inner station, could lead us to conclude that the main organic matter source is marine. However, as observed especially in the freshwater assemblage distribution, the land derived processes are important in the inner ría (Fig. 8). TOC/TN ratios are not suitable for quantitative approaches for the origin of the organic matter, although values <10 reflect that the main source of organic carbon is marine (Emerson and Hedges 1988; Meyers 1994). Surface river water was displaced northward due to the Coriolis effect generating a maximum of this factor.

PC2 is confined to the middle ría region, where oceanic processes (such as nutrient supply when upwelling occurs) and terrestrial processes take place.We interpret this factor as mixed terrestrial and oceanic conditions. In this way, high productivity species (*Chaetoceros* R. S.) related to upwelling development and riverine tracing species (*T. nitzschioides*) appear, as well as opal.

PC3 is linked to the oceanic influence and high productivity conditions when upwelling of ENACW occurs, since *P. sulcata* and *L. danicus* load positively in this factor. However diatom valves abundance load negatively, since this parameter is higher in the innermost areas where the high supply of the freshwater-benthic assemblage is important.

The rest of the factors extracted are related with postdepositional processes since this factors load on diatom species affected by dissolution due to their low silicified valves in the water column or in the sediments.

CONCLUDING REMARKS

In the water column, *Chaetoceros* taxa is linked to the development of high production conditions caused by upwelling. *L. danicus* proliferates after the upwelling under low nutrient levels and stratification and *P. sulcata* and benthic group appeared in the water column due to the resuspension of the sediment with high river runoff. In the outer areas of the ria, *P. sulcata* appearance in surface sediments is related to high productivity and upwelling development as well as *L. danicus* (after upwelling). Freshwater group tracks the intensity of the Lérez River plume. Moreover, *S. costatum* is related to riverine and freshwater input and inner estuarine processes whereas *T. nitzschioides* tolerates variable conditions but it is also related to river runoff. *Thalassiosira* spp. appear under continuous nutrient input. *Rhizosolenia* species respond to the winter upwelling blooms, under low nutrient contents in the surface waters.

Strong dissolution of the slightly silicified species occurred mostly at the water/sediment interface, e.g. *Rhizosolenia* spp. *S. costatum. Thalassiosira* species experience dissolution progressively from the low-deep water column and in the sediment. *T. nitzschioides* showed an strong enrichment of their relative percentage, both in the traps and in the sediment. *Chaetoceros* species and *L. danicus* are very well preserved in the sediment as resting spores. Benthic and freshwater species appears preferentially in sediments of the innermost areas. *P. sulcata* is one of the robust species that only appears in the sediments.

Freshwater group, crysophycean cysts and phytoliths document the geographical extension of the Lérez River plume and the entrance of fresher water from the southern mouth of the ría with high riverine discharges to the shelf from the Miño River.

Geochemical and micropaleontological proxies in the surface sediment reflected the strong contrast between the upwelling influenced area and the estuarine-dominated inner zone, with the appearance of a mixed zone where both processes occur. Moreover, postdepositional processes play also a role on the diatom species distribution. The study shows that the diatom distribution, species composition and biosiliceous remains in the surface sediments in the Pontevedra Ría are closely correlated with the oceanographic conditions and environmental variables e.g. freshwater discharges, nutrient input by upwelling and water column stratification. These remarks have implications for the use of thanatocoenosis downcore and fossil diatom assemblages together with geochemical and other paleoproxies for reconstruction of paleoceanographic conditions in the rías and nearby areas.

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Station	Longitude W	Latitude N	Mud content (%)	Organic Matter (%)	TOC (%)	TN (%)	Opal (%)	$CaCO_3$ (%)	TOC/TN	TOC/Si	TN/Si
8	8.69	42.41	29.51	19.39	5.68	0.48	0.4	8.28	11.89	34.01	2.86
9	8.70	42.41	37.52	25.2	7.42	0.66	1.34	11.49	11.31	13.26	1.17
10	8.72	42.40	18.92	21.26	3.99	0.54	2.21	19.56	7.44	4.32	0.58
11	8.74	42.39	32.61	20.32	4.02	0.53	2.73	16.19	7.58	3.53	0.46
12	8.76	42.38	27.83	18.26	3.43	0.43	2.55	16.33	7.92	3.22	0.41
13	8.79	42.36	11.60	12.94	2.16	0.24	1.91	31.14	8.94	2.71	0.30
14	8.83	42.36	3.04	6.01	0.6	0.08	0.85	26.81	7.76	1.70	0.22
15	8.88	42.35	22.80	10.13	1.57	0.16	1.75	38.18	9.93	2.15	0.22
16	8.90	42.32	14.66	11.11	1.7	0.18	1.7	23.72	9.22	2.40	0.26
N1	8.69	42.43	40.23	9.55	2.3	0.23	0.36	3.36	9.83	15.31	1.56
N2	8.70	42.42	31.48	21	5.78	0.58	1.04	9.97	10.03	13.31	1.33
N3	8.71	42.41	5.24	7.88	1.24	0.16	1.3	49.41	7.60	2.29	0.30
N4	8.73	42.41	26.81	24.32	4.67	0.70	4.97	21.90	6.66	2.25	0.34
N5	8.81	42.39	4.54	6.76	0.65	0.10	1.17	76.46	6.40	1.34	0.21
N6	8.86	42.38	7.88	7.75	1.33	0.10	1.3	38.4	12.66	2.45	0.19
N7	8.89	42.38	14.85	9.04	1.08	0.13	1.7	43.20	8.61	1.52	0.18
N8	8.89	42.36	26.24	14.25	2.15	0.26	2.13	20.59	8.24	2.41	0.29
N9	8.90	42.35	6.72	4.91	0.99	0.08	2.19	23.53	11.81	1.09	0.09
N10	8.91	42.38	4.08	6.99	1.02	0.08	1.82	52.32	11.98	1.34	0.11
S2	8.69	42.41	14.89	9.36	2.42	0.15	0.44	7.63	16.56	13.16	0.79
S3	8.70	42.40	8.47	16.5	5.16	0.26	0.75	26.59	20.15	16.48	0.82
S4	8.74	42.39	4.51	11.01	2.18	0.15	1.2	65.09	14.17	4.35	0.31
S5	8.77	42.35	20.78	8.55	1.43	0.21	1.72	20.75	6.80	2.00	0.29
S6	8.78	42.35	5.72	6.51	0.92	0.10	1.63	35.81	9.06	1.36	0.15
S8	8.84	42.30	18.50	10.9	2.05	0.23	1.06	45.46	8.90	4.64	0.52
S9	8.85	42.32	0.01	5	1	0.03	0.11	54.81	33.31	21.78	0.65
S10	8.85	42.35	10.30	9.42	1.61	0.14	0.89	43.79	11.25	4.35	0.39

Table 1 Sediment characterization at the sampling sites. Data from Dale and Prego (2002)
TOC: Total organic carbon
TN: Total nitrogen
Si: Total silicon

Station	Slide fraction	Counted valves	Diatom valves	Diatom fragments	Porifera	Phytoliths	Cingulum	Crysophycean cysts	Silicoflagellates	*A. pentasterias*	Radiolarians	Palinomorphs
			$\times 10^5$	$\times 10^5$	$\times 10^5$	$\times 10^5$	$\times 10^4$	$\times 10^4$	$\times 10^3$	$\times 10^3$	$\times 10^3$	$\times 10^3$
8	1/6	397	14.7	20.5	1.7	13.1	18.5	7.0	3.7	0	0	3.7
9	1/10	254	15.6	21.4	2.2	12.0	14.1	14.1	18.5	6.1	6.1	30.8
10	1/4	522	12.8	16.1	8.0	11.4	30.6	8.1	7.4	9.8	0	2.4
11	1/6	412	15.2	17.8	11.8	10.5	54.0	4.8	7.4	7.4	0	0
12	1/7	313	13.5	14.1	13.9	11.9	55.3	6.9	8.6	12.9	4.3	0
13	1/3	252	4.6	3.2	5.6	2.6	15.5	1.8	0	3.7	1.8	7.4
14	1	320	1.9	0.7	1.6	0.6	4.2	0.4	0.6	1.2	0	0.6
15	1/2	292	3.6	2.4	5.1	3.4	18.6	0.7	1.2	2.4	2.4	11.1
16	1/5	222	6.8	4.3	11.9	7.3	49.3	0.9	6.1	9.2	3.0	18.5
N1	1/3	266	4.9	8.7	0.6	3.5	5.3	0.7	0	0	1.8	3.7
N2	1/6	359	13.2	27.1	2.8	12.9	30.7	2.9	0	0	3.7	14.8
N3	1/6	328	12.1	22.5	3.4	8.7	26.2	4.0	0	3.7	0	7.4
N4	1/8	486	24.0	59.9	7.8	18.8	106.1	6.9	9.8	14.8	0	9.8
N5	1/8	458	22.6	14.3	6.1	3.2	47.9	9.3	14.8	4.9	4.9	0
N6	1/2	211	2.6	2.3	2.4	0.8	23.2	0.3	1.2	1.2	0	1.2
N7	1/2	290	3.5	1.9	3.5	1.6	22.0	0.3	2.4	9.8	3.7	6.1
N8	1/3	458	8.4	3.6	8.7	4.9	50.0	1.4	3.7	5.5	0	1.8
N9	1/3	420	7.7	1.8	2.4	0.9	21.6	0.3	0	3.7	0	11.1
N10	1/3	132	2.4	0.9	3.6	1.1	18.8	0	1.8	1.8	0	5.5
S2	1/2	345	4.2	8.5	0.5	3.3	9.1	1.4	0	0	0	6.1
S3	1/3	540	10.0	13.0	1.6	3.1	22.9	1.6	5.5	0	0	5.5
S4	1/8	493	24.3	32.3	4.9	4.0	87.9	4.4	19.7	14.8	0	0
S5	1/3	414	7.6	4.4	2.9	2.1	57.5	0.9	5.5	3.7	0	12.9
S6	1/4	484	11.9	6.2	4.9	3.7	68.8	2.7	2.4	7.4	0	0
S8	1/4	324	8.0	5.7	7.4	3.2	50.3	0.4	0	0	0	4.9
S9	1/5	0	0	0.1	0.1	0.03	1.2	0	0	0	0	0
S10	1/6	391	14.4	5.3	3.1	2.2	42.2	2.5	0	0	0	0
		Mean	10.0	11.8	4.8	5.6	35.3	3.1	4.4	4.6	1.1	6.1
		Max	24.3	59.9	13.9	18.8	106.1	14.1	19.7	14.8	6.1	30.8
		Min	0	0.1	0.1	0.03		0	0	0	0	0

Table 2 Absolute abundances per gram of dry sediment of the biosiliceous compounds (diatom valves, fragments of diatoms, porifera spicules, phytoliths, crysophycean cysts, radiolarians, silicoflagellates, and the dinoglagellate A. pentasterias) and palynomorphs

	Benthic	Freshwater	*Thalassiosira*	*T. nitzschioides*	*L. danicus*	*P. sulcata*	*Chaetoceros* R.S.	*S. costatum*	TOC	TN	Opal	$CaCO_3$	Diatom valves	Radiolarians	Crysophycean cysts	Palinomorphs	Porifera	Silicoflagellates	Phytoliths	*Rhizosolenia*	Mud	*A.pentasterias*
Benthic	1.000	.659**	-.065	-.482*	-.292	-.314	-.635**	.143	.611**	.525**	-.218	-.582**	.138	.185	.288	.302	-.225	-.010	.510**	-.290	.646**	-.203
Freshwater		1.000	-.061	-.338	-.146	.088	-.576**	.263	.606**	.495**	-.105	-.542**	.136	.296	.380	.539**	.116	.206	.522**	-.360	.558**	.007
Thalassiosira			1.000	.294	-.063	-.059	0.190	-.067	.243	.233	.366	.062	.256	-.084	.261	-.155	.300	.286	.261	.300	-.096	.300
T. nitzschioides				1.000	.240	.294	.662**	.170	-.368	-.358	.204	.300	-.041	-.267	-.389*	-.038	.133	.031	-.364	.372	-.402*	.133
L. danicus					1.000	.549**	0.101	-.114	-.149	-.019	.272	-.048	-.229	.087	-.165	.008	.397*	-.103	-.035	.067	.135	.172
P. sulcata						1.000	0.067	-.090	-.213	-.027	.413*	.031	-.240	.162	-.256	.090	.635**	-.090	.001	.163	.119	.360
Chaetoceros R.S.							1.000	-.108	-.404*	-.308	.293	.360	.216	-.139	-.035	-.235	.141	.125	-.320	.292	-.430*	.186
S. costatum								1.000	.209	.127	-.074	.042	.439*	-.113	.129	-.054	.127	.411*	.214	-.234	.047	.300
TOC									1.000	.890**	.135	-.588**	.437*	.279	.636**	.455*	.065	.387*	.761**	-.338	.679**	.099
TN										1.000	.470*	-.584**	.531**	.267	.681**	.385*	.337	.396*	.914**	-.336	.762**	.339
Opal											1.000	-.117	.380	.000	.239	.116	.630**	.269	.513**	-.008	.224	.703**
$CaCO_3$												1.000	.115	-.044	-.111	-.359	-.039	.165	-.467*	.318	-.733**	.081
Diatom valves													1.000	.164	.731**	.005	.337	.734**	.624**	-.293	.209	.554**
Radiolarians														1.000	.481*	.503**	.193	.402*	.236	-.050	.366	.208
Crysophycean cysts															1.000	.279	.238	.747**	.686**	-.283	.388*	.416*
Palinomorphs																1.000	-.085	.211	.307	-.194	.385*	.024
Porifera																	1.000	.315	.428*	-.159	.249	.646**
Silicoflagellates																		1.000	.385*	-.250	.164	.655**
Phytoliths																			1.000	-.357	.634**	.453*
Rhizosolenia																				1.000	-.279	-.055
Mud																					1.000	.100

Table 3 Pearson correlation table

**p<0.01

*p<0.05

N=27

Benthic group	Water colum	Sediment traps	Sediment
***Achnanthes* spp.** Bory 1822			X
Achnanthes brevipes Agardh 1824			X
***Amphora* spp.** (Ehrenberg) Kützing 1844	X	X	X
Auliscus sculptus (Smith) Ralfs in Pritchard 1864			X
***Campylodiscus* spp.** Ehrenberg ex Kützing 1844			X
Campyloneis grevillei (Smith) Grunow 1867			X
Catenula adhaerens (Mereschkowsky) Mereschkowsky 1903			X
Cerataulus radiatus (Roper) Ross 1986			X
Cerataulus turgidus Ehrenberg 1843			X
***Cocconeis* spp.** Ehrenberg 1837	X	X	X
Cocconeis californica Grunow 1881			X
Cocconeis costata Gregory 1855		X	X
Cocconeis dirupta Gregory 1857			X
Cocconeis disculoides Hustedt 1955			X
Cocconeis disculus (Schumann) Cleve 1895			X
Cocconeis distans Gregory 1855		X	
Cocconeis pediculus Ehrenberg 1838			X
Cocconeis peltoides Hustedt 1939			X
Cocconeis placentula Ehrenberg 1838			X
Cocconeis pseudomarginata Gregory 1857			X
Cocconeis scutellum Ehrenberg 1838		X	X
***Delphineis* spp.** Andrews 1977			X
Delphineis surirella (Ehrenberg) Andrews 1981			X
Dimeregramma marinum (Gregory) Ralfs in Pritchard 1861			X
Dimeregramma minor (Gregory) Ralfs in Pritchard 1861			X
***Diploneis* spp.** (Ehrenberg) Cleve 1894	X		X
Diploneis bombus (Ehrenberg) Ehrenberg ex Cleve 1894		X	X
Diploneis cabro (Ehrenberg) Cleve 1894			X
Diploneis didyma (Ehrenberg) Cleve 1894			X
Diploneis interrupta (Kützing) Cleve 1894			X
Diploneis notabilis (Greville) Cleve 1894			X
Diploneis papula (A. Schmidt) Cleve 1894			X
Diploneis smithii (Brébisson ex Smith) Cleve 1894		X	X
Eunotogramma marinum (Smith) Peragallo ex vanLand 1978			X
Grammatophora angulosa Ehrenberg 1840			X
***Grammatophora* spp.** Ehrenberg 1840			X
Grammatophora marina (Lyngbye) Kützing 1844	X	X	X
Grammatophora oceanica (Ehrenberg) Grunow 1881			X
Grammatophora serpentina (Ralfs) Ehrenberg 1844			X
***Gyrosigma* spp.** Hassall 1845			X
Gyrosigma fasciola (Ehrenberg, 1839) Griffith and Henfrey, 1856	X		
***Hantzschia* spp.** Grunow 1877			X
***Licmophora* spp.** Agardh 1827		X	X
Licmophora flabellata (Carmichael) Agardh 1830		X	
***Mastogloia* spp.** (Thwaites) Smith 1856			X
Mastogloia pseudoexigua Cholnoky 1956			X
***Navicula* spp.** Bory 1822	X		X
Navicula cancellata Donkin 1872		X	
Navicula digitoradiata (Gregory) Ralfs in Pritchard 1861		X	
Navicula distans (Smith) Ralfs in Pritchard 1861	X		X
Navicula forcipata Greville 1859			X
Navicula palpebralis (de Brébisson) Smith 1853		X	X
Navicula peregrina (Ehrenberg) Kützing 1844			X
Navicula transitrans (Grunow) Cleve 1883		X	
Nitzschia panduriformis Gregory 1857			X
***Opephora* spp.** Petit 1888			X
Opephora schulzii (Brockmann 1950) Simonsen 1962			X
Petroneis monilifera (Gregory) Stickle & Mann 1990			X
Plagiogramma pulchellum Greville 1859			X
Plagiogramma staurophorum (Gregory) Heiberg 1863			X
Pleurosigma acutum Norman ex Ralfs in Pritchard 1861		X	
Pleurosigma angulatum (Quekett) Smith 1853	X		
Pleurosigma elongatum Smith 1852	X		
***Pleurosigma* spp.** Smith 1852	X	X	X
Podosira stelligera (Bailey) Mann 1907	X	X	X
Psammodiscus nitidus (Gregory) Round and Mann 1990			X
Rhabdonema minutum Kützing 1844			X

Rhabdonema adriaticum Kützing 1844	X		
Striatella unipunctata (Lyngbye 1819) Agardh 1832	X		
Surirella fastuosa (Ehrenberg) Kützing 1844	X		X
***Toxarium* spp.** Bailey 1854			X
Trachyneis aspera (Ehrenberg) Cleve 1894		X	X
***Trachyneis* spp.** Cleve 1894		X	
Tryblionella Smith (1853)			X
Tryblionella coarctata (Grunow) Mann in Round et al., 1990			X
Tryblionella punctata Smith 1853			X

	Water colum	Sediment traps	Sediment
Freshwater group			
Achnanthes lanceolata (de Brébisson in Kützing) Grunow in Cleve et Grunow 1880			X
Achnanthes minutissima Kützing 1933		X	
***Aulacoseria* spp.** Thwaites 1848			X
Aulacoseria granulata (Ehrenberg) Ralfs in Pritchard 1861			X
Aulacoseria islandica (O. Müller) Simonsen 1979	X		X
Ctenophora pulchella (Ralfs ex Kützing) Williams et Round 1986			X
***Cyclotella* spp.** (Kützing) de Brébisson 1838			X
Cyclotella litoralis Lange and Syvertsen 1989			X
Cyclotella menenghiniana Kützing 1844		X	X
Cyclotella ocelata Pantoscek 1912			X
***Cymbella* spp.** Agardh 1830			X
***Diatoma* spp**. Bory 1824			X
Diatoma hyemalis (Roth) Heiberg 1863			X
Diatoma vulgare Bory 1824			X
***Epithemia* spp.** Kützing 1844			X
Epithemia adnata (Kützing) Rabenhorst 1853			X
Epithemia argus (Ehrenberg) Kützing 1844			X
***Eunotia* spp.** Ehrenberg 1837			X
Eunotia arcus Ehrenberg 1837			X
Eunotia pectinalis (O.F. Müller) Rabenhorst, 1864			X
Eunotia pectinalis var. minor (Kützing) Rabenhorst 1864			X
Eunotia triodon Ehrenberg 1837			X
Fragilaria crotonensis Kitton 1869	X	X	
Fragilaria vaucheriae (Kützing) Petersen 1938			X
***Fragilariforma* spp.** Williams and Round 1988			X
***Fragillaria* spp.** Lyngbye 1819	X		X
***Gomphocymbela* spp.** Muller 1905			X
***Gomphonema* spp.** Ehrenberg 1832			X
Gomphonema acuminatum Ehrenberg 1832			X
Gomphonema truncatum Ehrenberg 1832			X
Hannaea arcus (Ehrenberg) Patrick 1966			X
Hantzschia amphioxys (Ehrenberg) Grunow in Cleve and Grunow 1880			X
***Luticola* spp.** (Kützing) Mann 1990			X
Melosira moniliformis (Müller) Agardh 1824	X		
Meridion circulare (Greville) Agardh 1831			X
***Pinnularia* spp.** Ehrenberg 1843			X
Pinnularia acoricola Hustedt 1934			X
Pinnularia borealis Ehrenberg 1843			X
***Sellaphora* spp.** Mereschkowsky 1902			X
Sellaphora pupula (Kützing) Mereschkowsky 1902			X
***Stauroneis* spp.** Ehrenberg 1843			X
***Staurosirella* spp.** Williams and Round 1988			X
Staurosirella pinnata (Ehrenberg) Williams and Round 1987			X
***Stephanodiscus* spp.** Ehrenberg 1845			X
***Synedra* spp.** Ehrenberg 1830			X
Synedra closterioides Grunow 1881	X		
Synedra ulna (Nietzsche) Ehrenberg 1838		X	X
Synedra undulata (Bailey) Gregory 1861		X	
***Tabellaria* spp.** Ehrenberg 1840		X	X
Tabellaria flocculosa (Roth) Kützing 1844			X

	Water colum	Sediment traps	Sediment
Other species			
Actinocyclus curvatulus Janisch 1878			X
Actinocyclus octonarius Ehrenberg 1838			X

Actinoptychus senarius (Ehrenberg) Ehrenberg 1843	X		X
Actinoptychus splendens (Shadbolt) Ralfs ex Pritchard 1861			X
***Anaulus* spp.** Ehrenberg 1844			X
Anaulus balticus Simonsen 1959			X
Anaulus minutus Grunow in van Heurck 1881			X
Asterionella formosa Hassall 1850	X		
Asterionellopsis glacialis (Castracane) Round in Round et al., 1990	X	X	
Asteromphalus flabellatus (Brébisson) Greville 1859			X
Bacteriastrum delicatulum Cleve 1897	X		
Bacteriastrum hyalinum Lauder 1864	X	X	
Biddulphia alternans (J.W. Bailey) Van Heurck 1885		X	X
Bidulphia pulchella Gray 1831			X
Biddulphia obtusa (Kützing) Ralfs in Pritchard 1861			X
***Caloneis* spp.** Cleve 1894			X
Cerataulina pelagica (Cleve) Hendey 1937	X	X	
***Chaetoceros* spp.** Ehrenberg 1844	X	X	
***Chaetoceros* spp.** R.S. Ehrenberg 1844	X	X	X
Chaetoceros affinis Lauder 1864	X	X	X
Chaetoceros atlanticus Cleve 1873	X		
Chaetoceros brevis Schütt 1895		X	
Chaetoceros cinctus Gran 1897	X		X
Chaetoceros compressus Lauder 1864	X		X
Chaetoceros constrictus Gran 1897	X		
Chaetoceros convolutus Castracane 1886	X		
Chaetoceros curvisetus Cleve 1889	X	X	
Chaetoceros danicus Cleve 1889	X		
Chaetoceros debilis Cleve 1894	X		X
Chaetoceros decipiens Cleve 1873	X	X	
Chaetoceros densus Cleve 1901	X	X	
Chaetoceros diadema (Ehrenberg) Gran 1897			X
Chaetoceros didymus Ehrenberg 1845	X	X	X
Chaetoceros neogracilis Schütt 1895	X		
Chaetoceros laciniosus Schütt 1895	X		
Chaetoceros lorenzianus Grunow 1863	X	X	X
Chaetoceros perpusillus Cleve 1896	X		
Chaetoceros pseudocurvisetus Mangin1910	X		
Chaetoceros radicans Schütt 1895	X		
Chaetoceros seychelarum Karsten 1907			X
Chaetoceros socialis Lauder 1864	X	X	
Chaetoceros subsecundus (Grunow in Van Heurck) Hustedt 1930		X	
Corethron criophilum Castracane 1886	X		
***Coscinodiscus* spp.** (Ehrenberg) Hasle and Sims 1986	X	X	
Coscinodiscus argus Ehrenberg 1838			X
Coscinodiscus concinnus Smith 1856	X		
Coscinodiscus decrescens Grunow in Schmidt 1878			X
Coscinodiscus radiatus Ehrenberg 1841	X		X
Cylindrotheca closterium (Ehrenberg) Reiman and Lewin 1964	X		
Detonula pumila (Castracane) Schütt 1896	X	X	
Ditylum brightwellii (West) Grunow in Van Heurck 1883	X	X	
Eucampia zodiacus Ehrenberg 1840	X	X	
Fragilariopsis doliolus (Wallich) Medlin and Sims 1993			X
Guinardia delicatula (Cleve) Hasle 1996	X	X	
Guinardia flaccida (Castracane) Peragallo 1892	X	X	
Guinardia striata (Stoltherfoth) Hasle1996	X	X	
Hemiaulus hauckii Grunow in Van Heurck,1882	X		
Hemidiscus cuneiformis Wall 1860			X
Huttoniella reichardtii Karsten 1928			X
Lauderia annulata Cleve 1873	X		
Leptocylindrus danicus Cleve 1889	X	X	
***Leptocylindrus danicus* R.S.** Cleve 1889			X
Leptocylindrus mediterraneus (H. Peragallo, 1888) Hasle 1975	X		
Leptocylindrus minimus Gran 1915	X	X	
***Navicula* spp.** Bory 1822	X		
***Nitzschia* spp.** Hassall 1845	X		X
Nitzschia bicapitata Cleve 1901			X
Nitzschia longissima (Brébisson in Kützing) Ralfs in Pritchard 1861	X	X	
Odontella mobiliensis (Bailey) Grunow 1884	X	X	X
Paralia sulcata (Ehrenberg) Cleve 1873	X	X	X
Planktoniella sol (Wallich) Schütt 1892			X
***Pseudonitzschia* spp.** Peragallo in Peragallo 1900	X		X
Pseudonitzschia pungens (Grunow ex Cleve) Hasle 1993		X	

Pseudonitzschia delicatissima (Cleve) Heiden in Heiden and Kolbe 1928	X	X	
***Rhizosolenia* spp.** Brightwell 1858		X	X
Rhizosolenia alata Brightwell 1858	X		
Rhizosolenia fragilissima Bergon 1903	X	X	
Rhizosolenia hebetata (Bail) Gran 1904	X	X	
Rhizosolenia robusta Norman 1861	X		
Rhizosolenia setigera Brightwell 1858	X	X	
Rhizosolenia shrubsolei Cleve 1881	X		
Rhizosolenia styliformis Brightwel 1858	X		
Roperia tesselata (Roper) Grunow ex Pelletan 1883			X
Skeletonema costatum (Greville) Cleve 1878	X	X	X
Stephanopyxis turris (Greville and Arnott) Ralfs ex Pritchard 1861	X		
Thalassionema nitzschioides (Grunow) Mereschkowsky 1902	X	X	X
Thalassionema frauenfeldii (Grunow) Hallegraeff 1986	X		
***Thalassiosira* spp. (**Cleve) Hasle 1973	X	X	
Thalassiosira angulata (Gregory) Hasle 1978		X	
Thalassiosira anguste-lineata (Schmidt) Fryxell et Hasle 1977	X	X	
Thalassiosira levanderi Van Goor 1924	X	X	
Thalassiosira nordenskiöldii Cleve 1873	X		
Thalassiosira oestrupii (Ostenfeld) Hasle 1972		X	
Thalassiosira rotula Meunier 1910	X	X	
Thalassiothrix longissima Cleve and Grunow 1880	X		
Tryblionella navicularis (Brébisson ex Kützing) Ralfs in Pritchard 1861			X

Taxonomic appendix

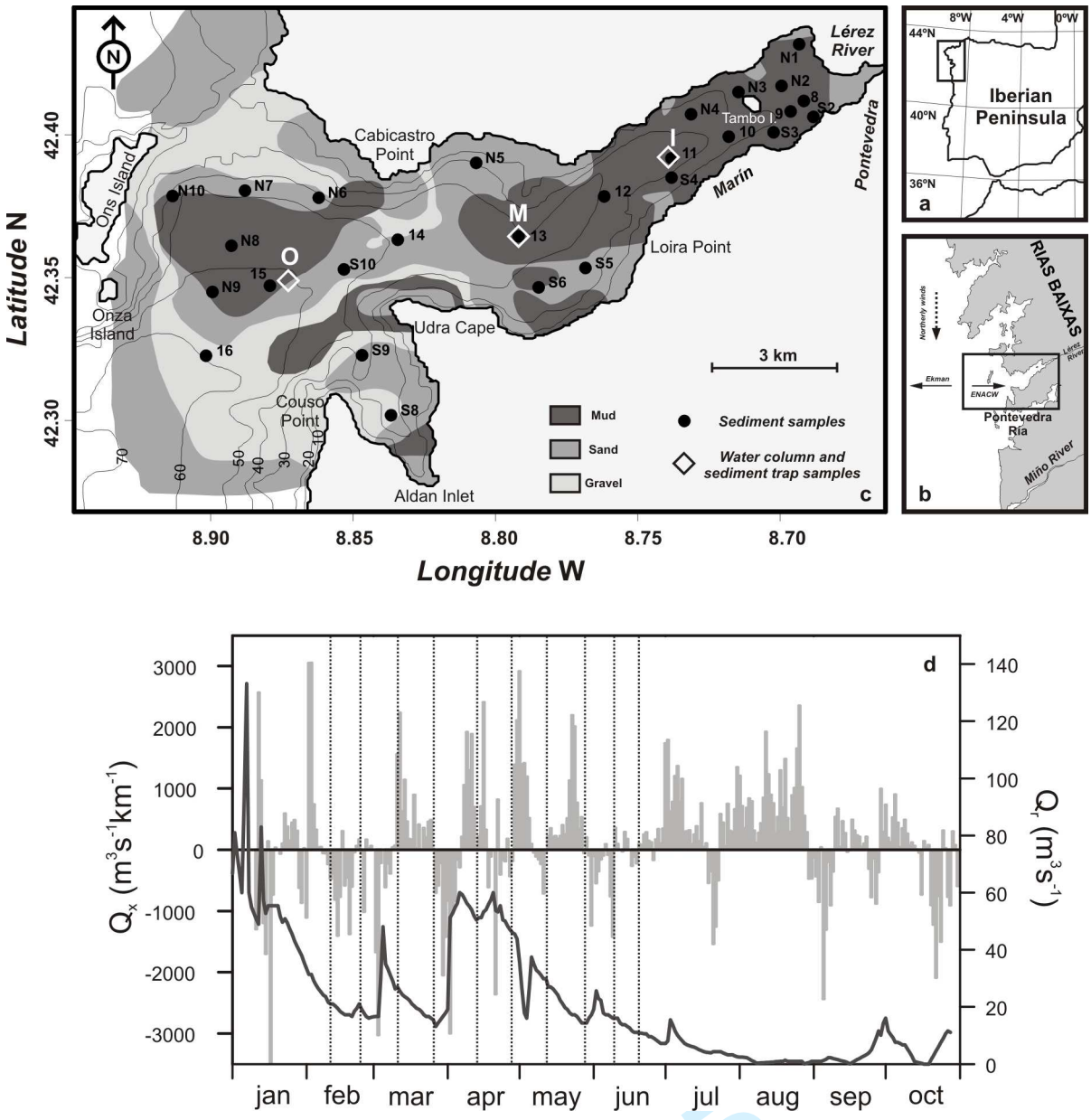


Fig. 1 a) General map of the study area. b) Location of the Pontevedra Ría. Schema of the upwelling phenomena and circulation. *ENACW*: Eastern North Atlantic Central Water c) Schematic illustration of the physiography and surface sample locations of the Pontevedra Ría. Schematic map showing the location of the bed sediment sampling (black circles) and grain size distribution (modified from Vilas et al., 2005). White diamonds indicate the stations were sediment traps were moored and the water column phytoplankton sampling carried out (I: Inner; M: Middle, O: Outer). Depth contours in metres. d) The solid line indicates the Lérez River daily discharge during January-October 1998 (Q_r values in m^3s^{-1}). Grey bars show the daily variations of the Upwelling Index (Q_x $m^3s^{-1}km^{-1}$) at point 43ºN 11ºW. Dashed lines indicate the water column sampling dates.

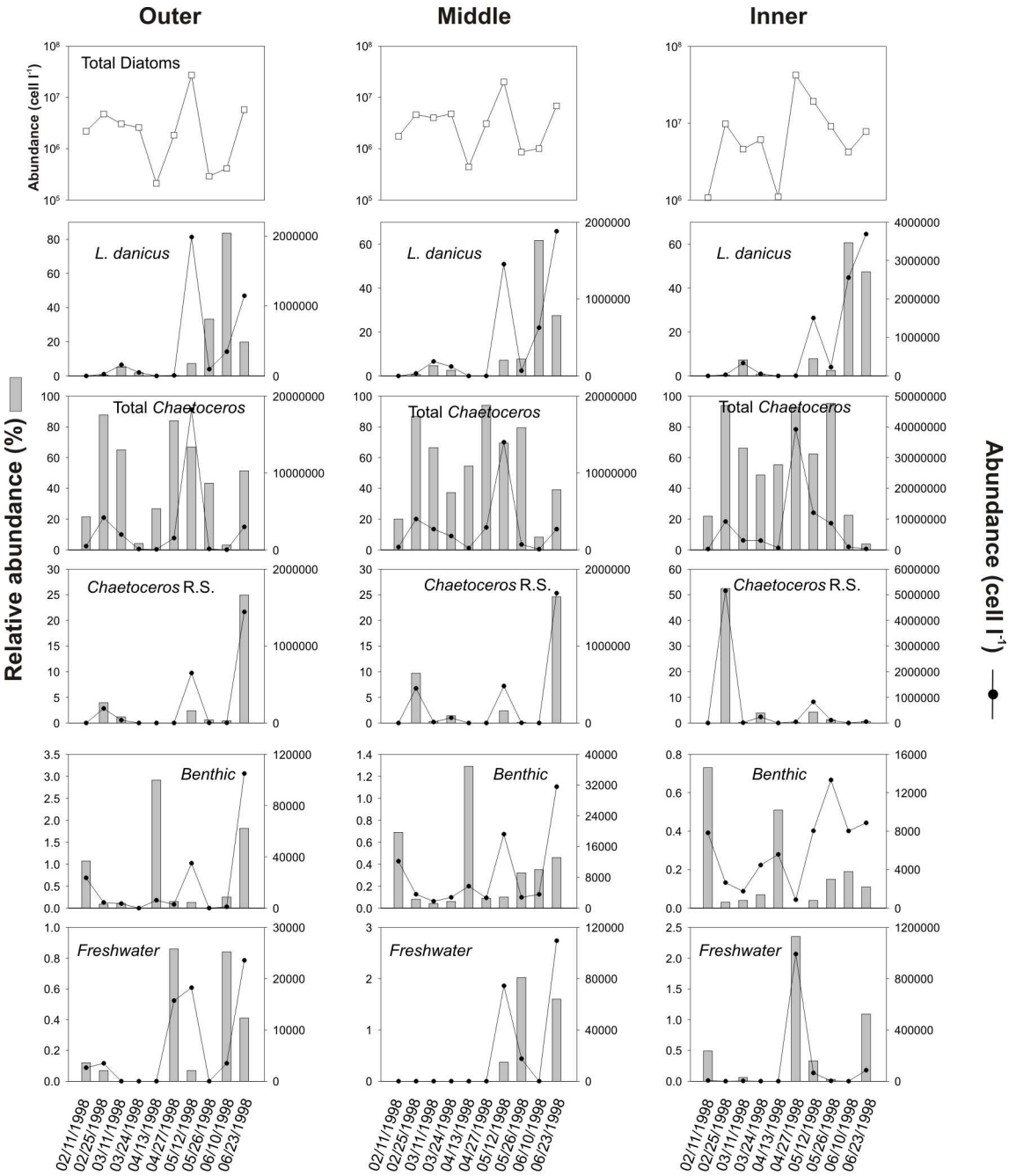


Fig. 2 Temporal variations of the standing stocks of total diatoms and the main diatom groups abundance in the water column (cell l^{-1}) at the three sampling sites. Note the logarithmic scale in the diagram showing the total diatom abundance

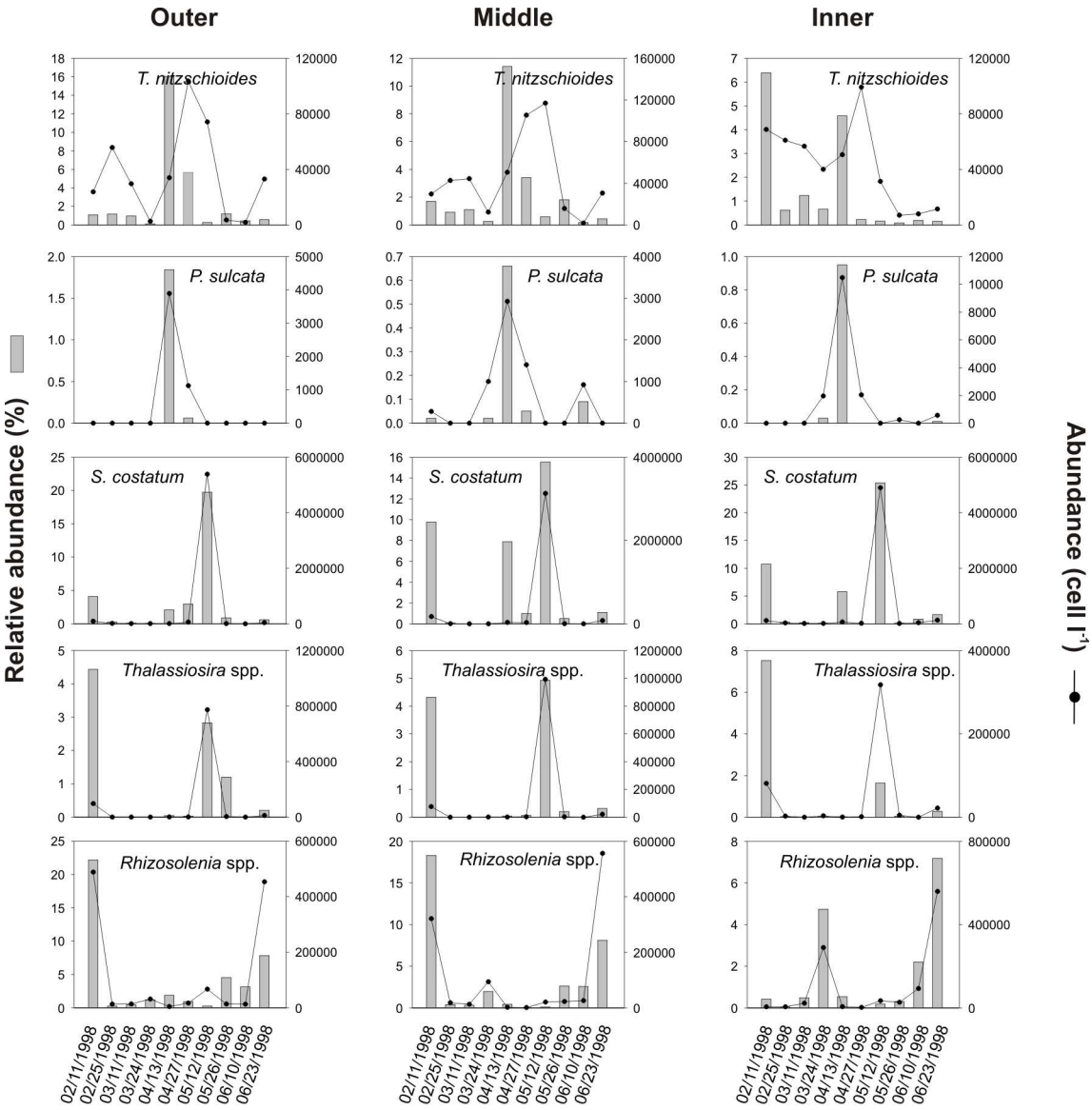


Fig. 2cont Temporal variations of the standing stocks of total diatoms and the main diatom groups abundance in the water column (cell l^{-1}) at the three sampling sites. Note the logarithmic scale in the diagram showing the total diatom abundance

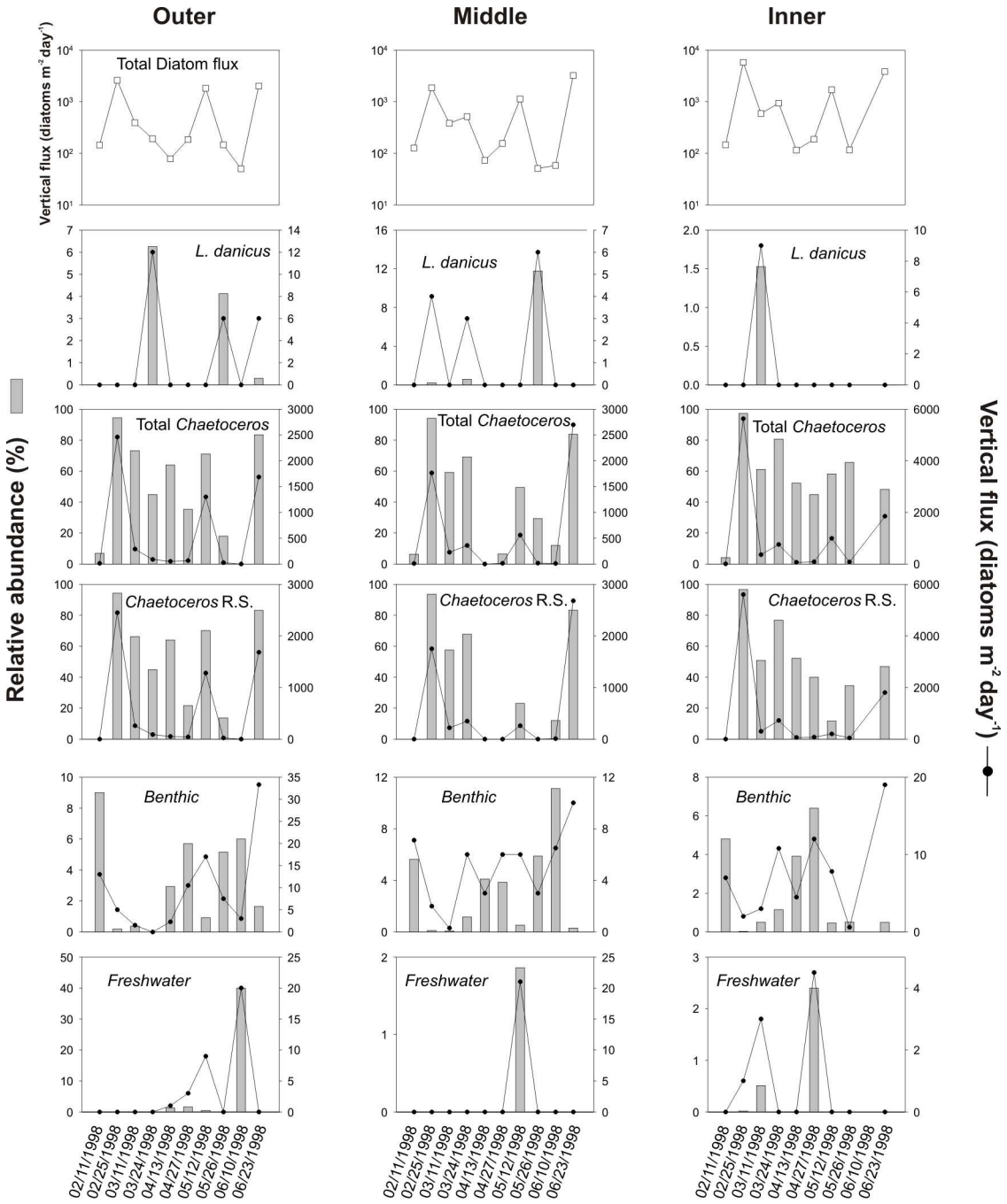
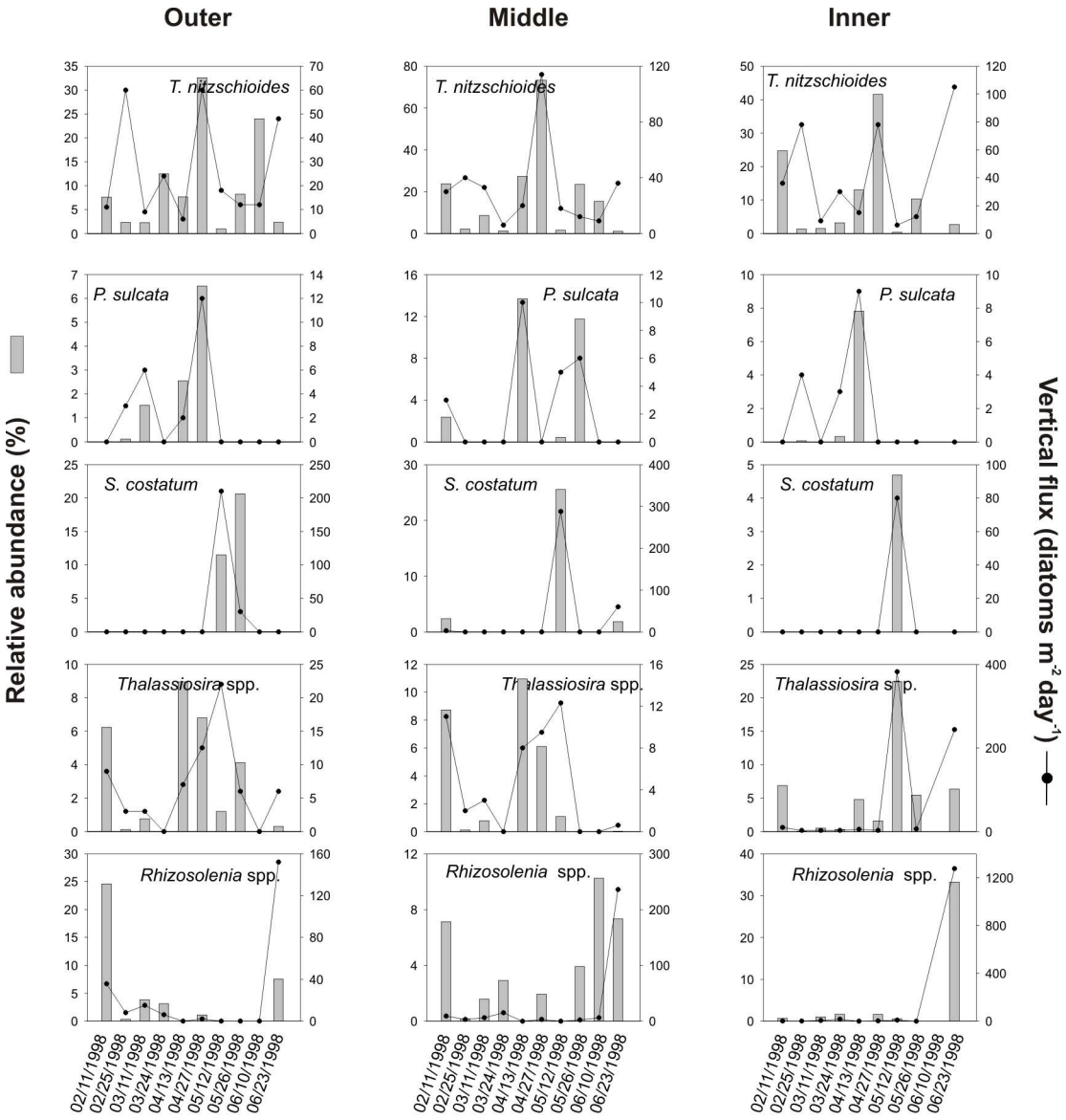


Fig. 3 Seasonal patterns of the total diatom and the main diatom community groups vertical flux in the sediment traps (diatom m^{-2} day^{-1}) at the inner, middle and outer sampling sites (I, M, O). Note the logarithmic scale in the diagram showing the total diatom downward flux



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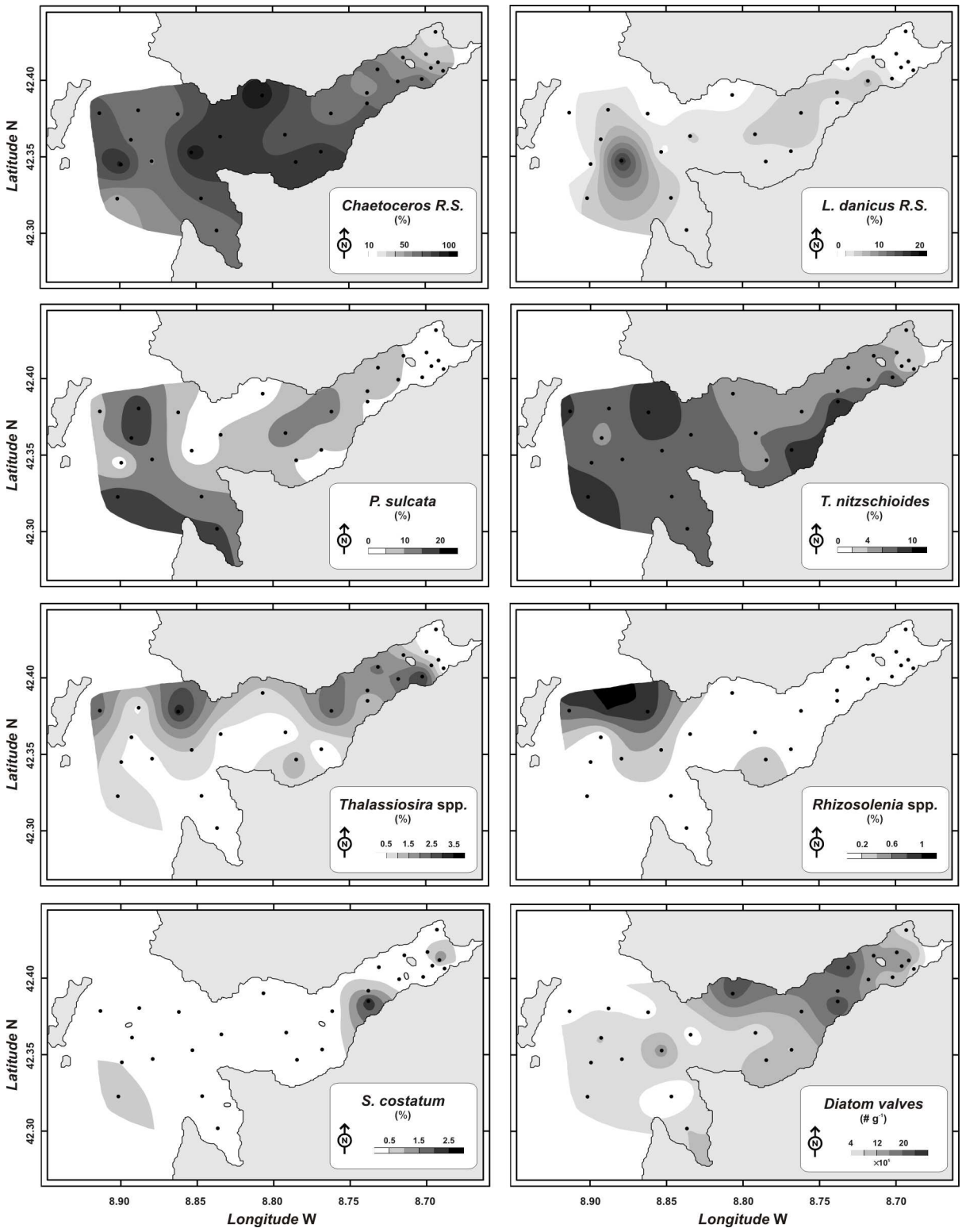


Fig. 4 Contour plots of the relative abundance of the main diatom species found in the superficial sediment of the Pontevedra Ría

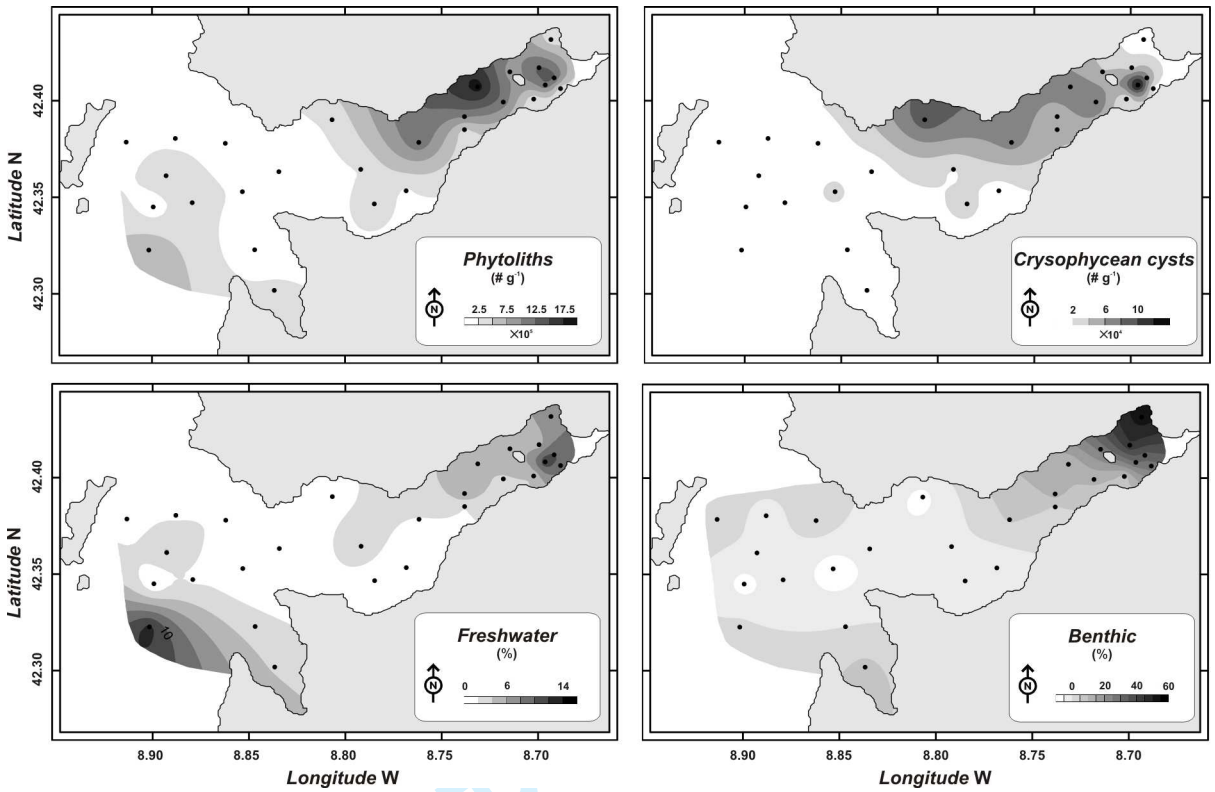


Fig. 5 Contour plots of the abundance per gram of sediment of the crysophycean cysts, phytoliths and relative abundance of the benthic and freshwater diatom groups

Factor loadings

	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6
A. pentasterias	0.369	**0.787**	0.022	0.118	-0.128	-0.068
Benthic	**0.640**	**-0.587**	-0.044	-0.145	-0.047	0.121
$CaCO_3$	**-0.568**	0.390	-0.412	0.338	0.072	-0.122
TOC	**0.876**	-0.152	-0.078	-0.192	0.104	0.166
Crysophycean cysts	**0.763**	0.246	-0.374	0.135	0.279	-0.170
Chaetoceros R.S.	-0.429	**0.622**	-0.171	-0.075	0.196	0.115
Freshwater	**0.698**	-0.338	0.151	0.179	-0.126	0.319
L. danicus	-0.100	0.310	**0.671**	0.118	-0.075	-0.064
Mud	**0.778**	-0.193	0.378	-0.074	0.003	-0.017
TN	**0.921**	0.086	0.085	-0.257	0.060	-0.037
Opal	0.315	**0.716**	0.313	-0.293	0.038	-0.105
Palinomorphs	0.479	-0.175	0.248	0.359	0.360	**0.437**
Phytoliths	**0.901**	0.171	0.034	-0.224	-0.059	-0.094
Porifera	0.317	**0.694**	0.398	0.026	-0.228	-0.172
P. sulcata	-0.069	0.417	**0.776**	0.220	-0.116	0.070
Radiolarians	0.429	0.048	0.133	**0.619**	**0.510**	-0.056
Rhizosolenia	-0.473	0.168	0.084	-0.229	**0.468**	0.262
S. costatum	0.252	0.149	-0.351	0.194	**-0.683**	**0.406**
Silicoflagellates	**0.529**	**0.525**	-0.434	0.354	0.057	0.098
Thalassiosira	0.137	0.468	-0.180	**-0.557**	0.305	0.196
T. nitzschioides	-0.459	**0.519**	0.067	-0.089	-0.043	**0.654**
Diatom valves	**0.578**	0.497	**-0.535**	0.017	-0.107	-0.063

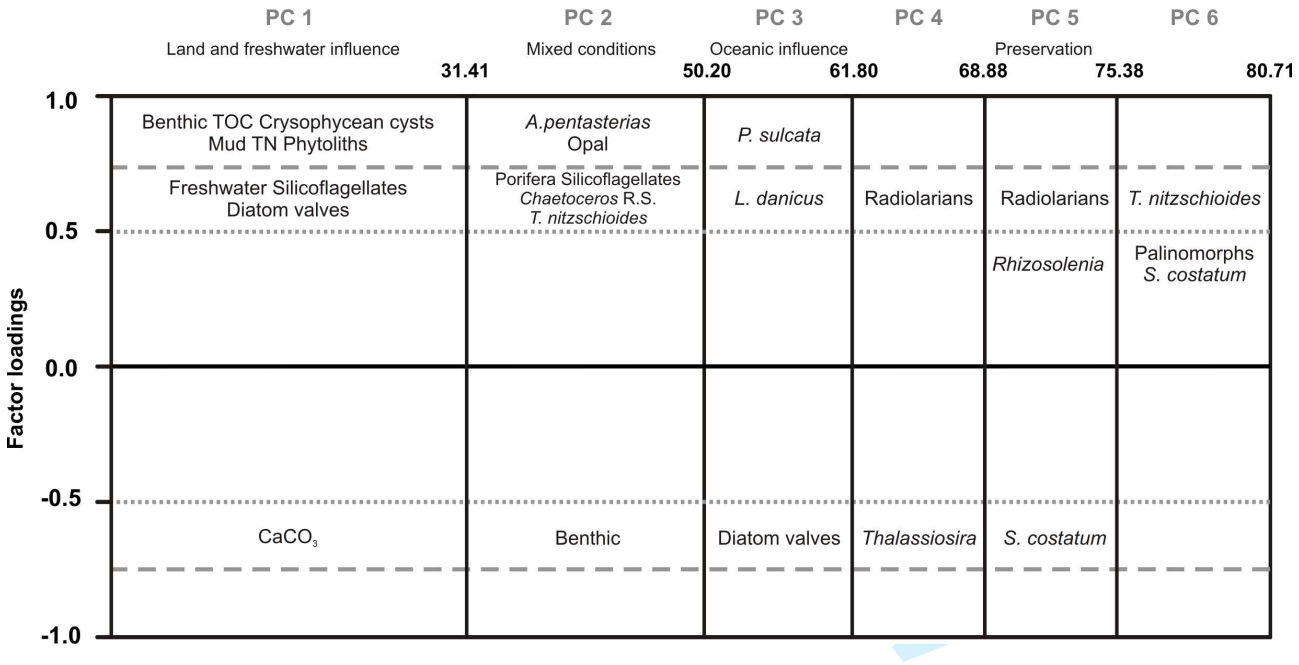


Fig. 6 Diagram showing the factor loadings obtained by the R-mode factor analysis. On the schema below numbers in bold are the percentage of the variance explained by the statistical analysis.

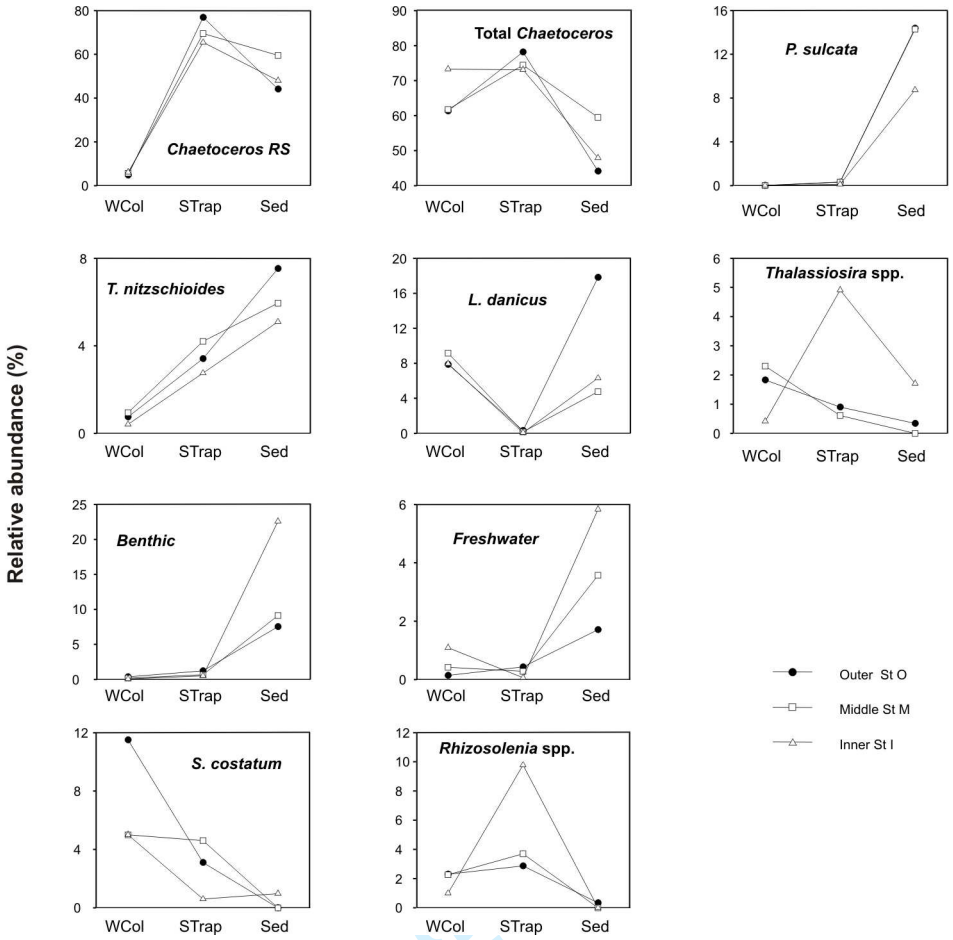


Fig. 7 Mean relative abundances of diatoms in the water column, traps and sediment for each station during the sampling

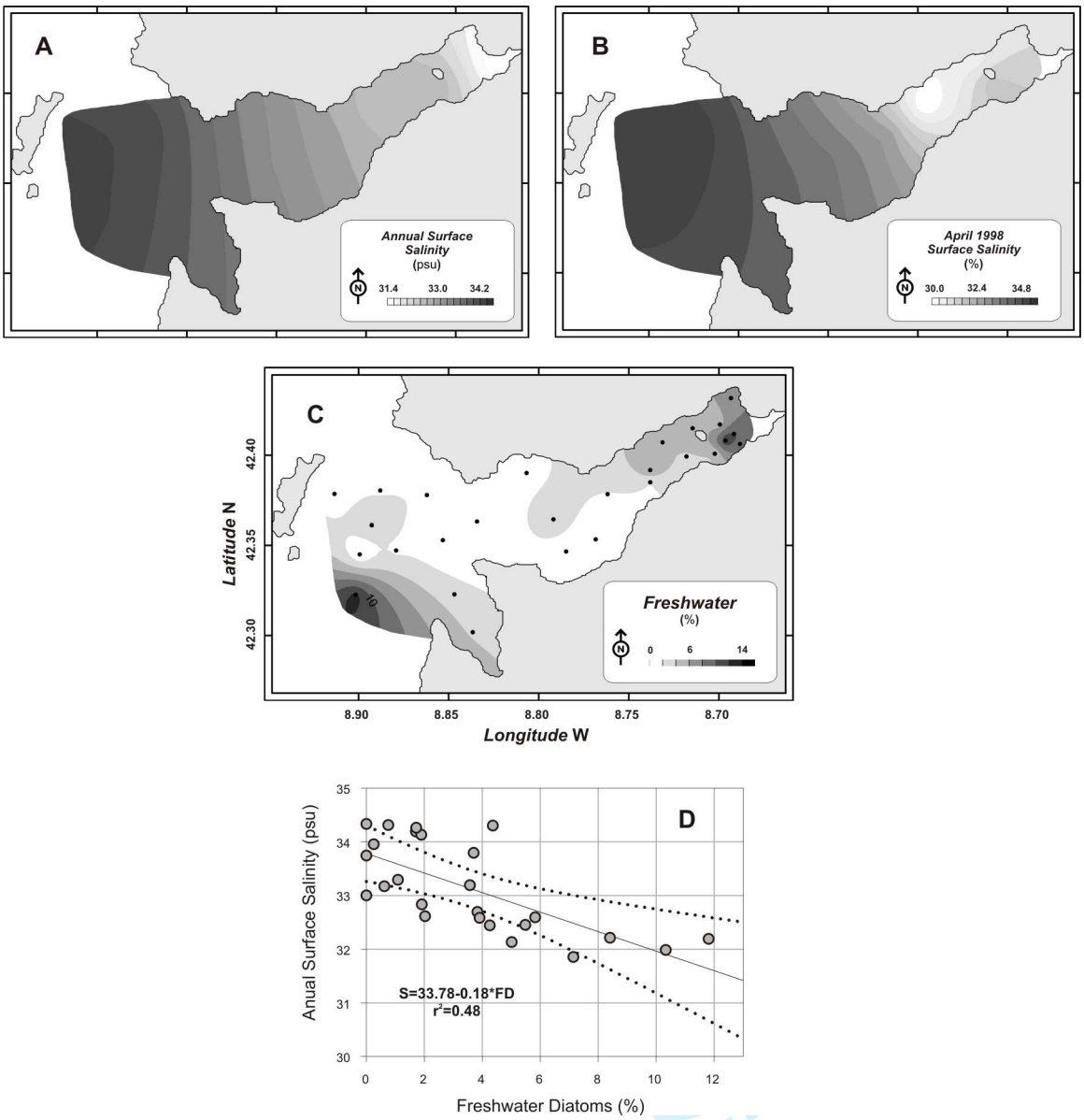
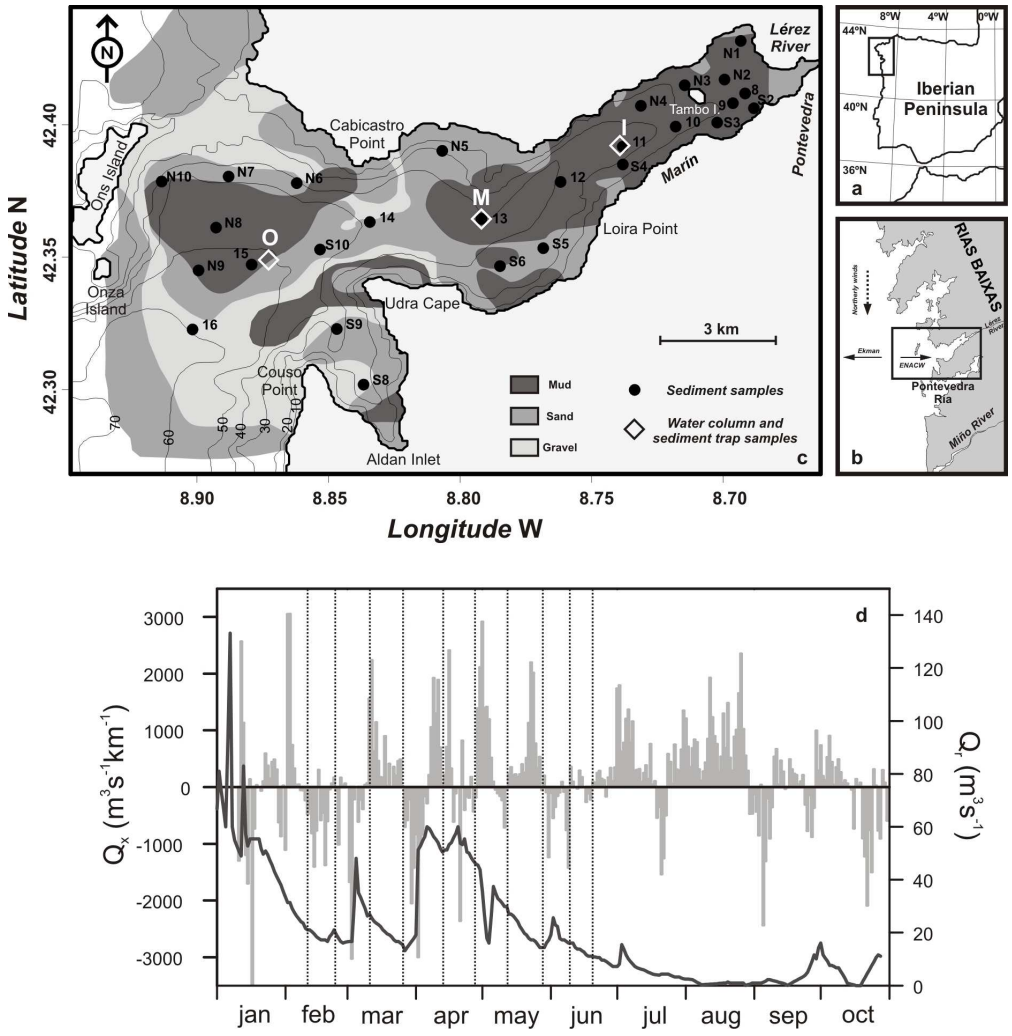


Fig 8 A) Spatial distribution of annual mean surface salinity (oct-1997 to oct-1998) B) Spatial distribution of sea-surface salinity during 13th April 1998, under conditions of high river runoff. C) Freshwater diatom distribution in surface sediments. D) Correlation between modern freshwater diatom percentages, and the annual mean of sea-surface salinity obtained from the figure A. Note that St. 16 was not included in the correlation. Dotted lines indicate the confidence intervals at 99%



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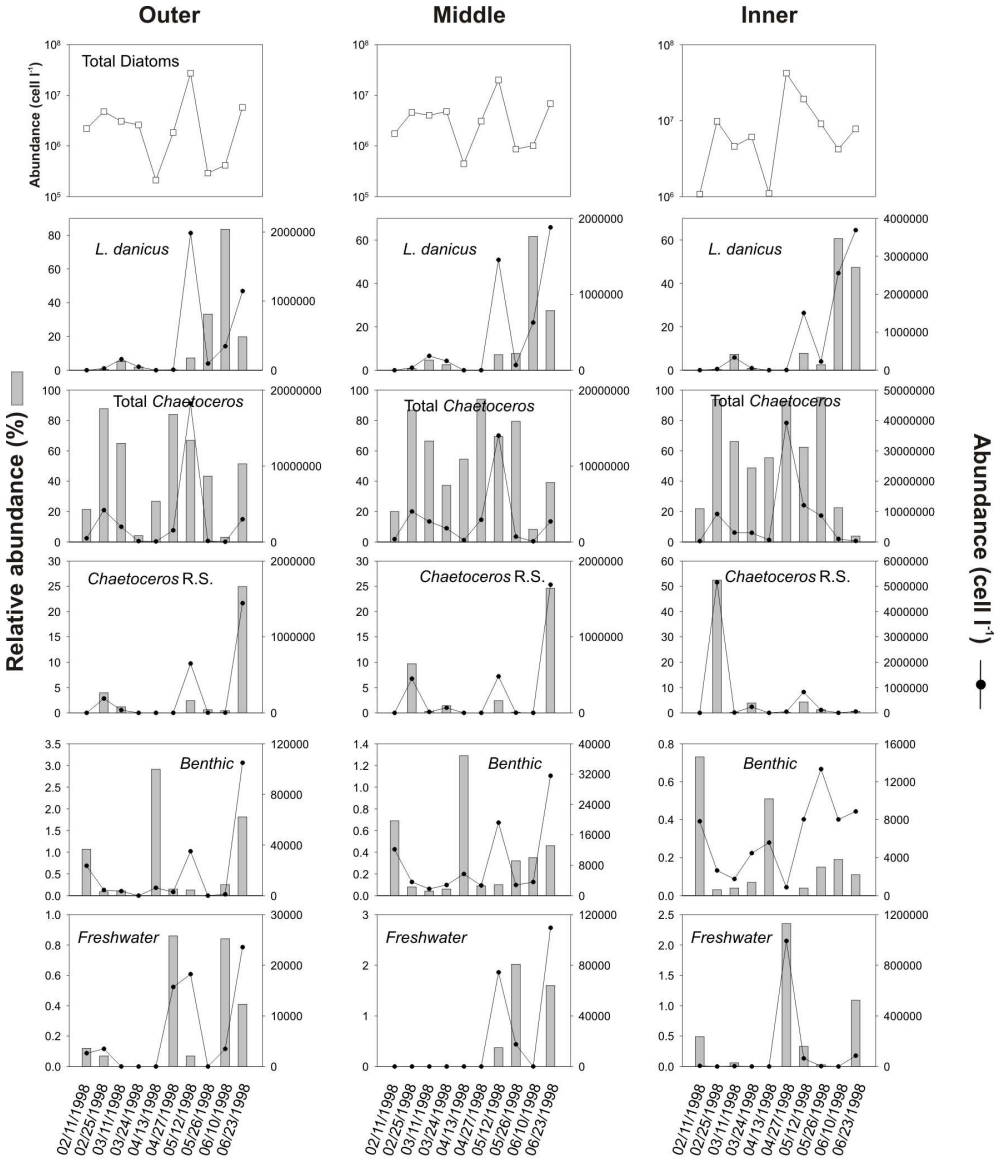

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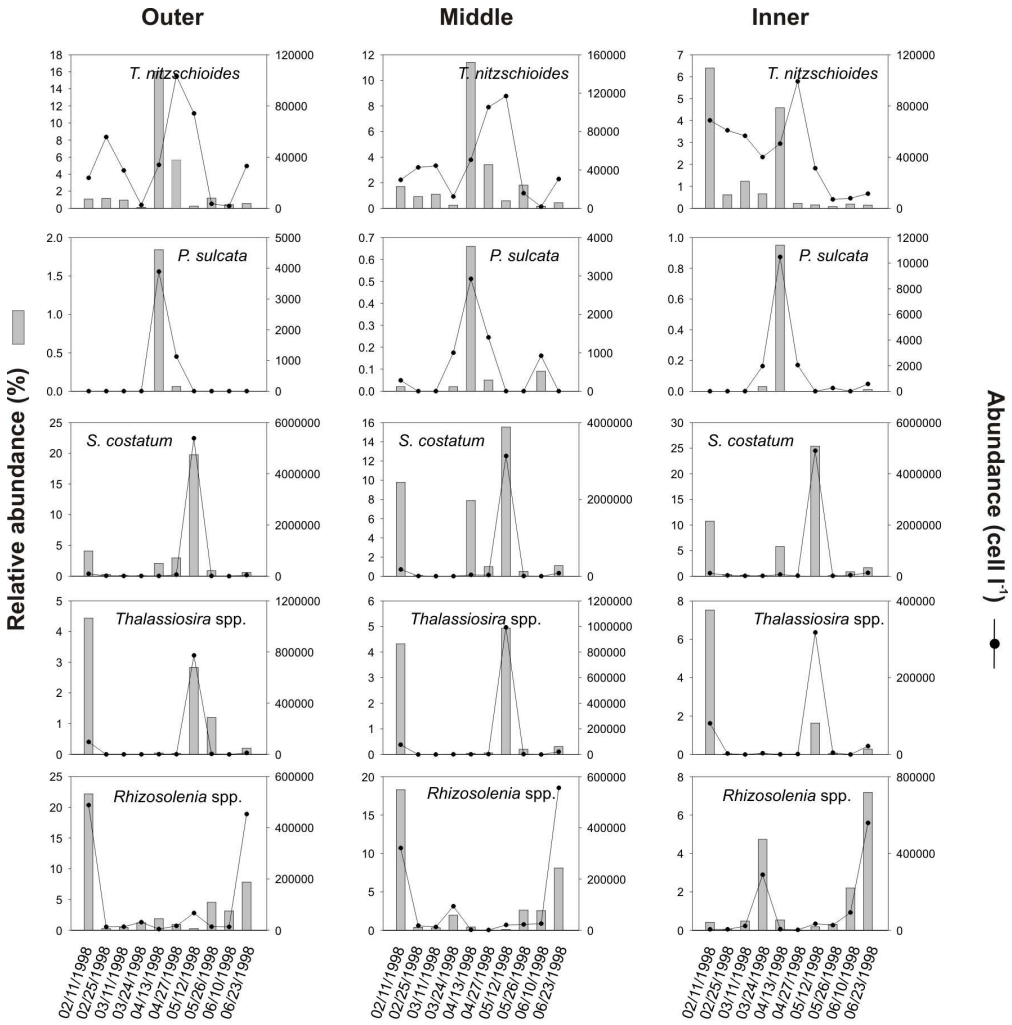

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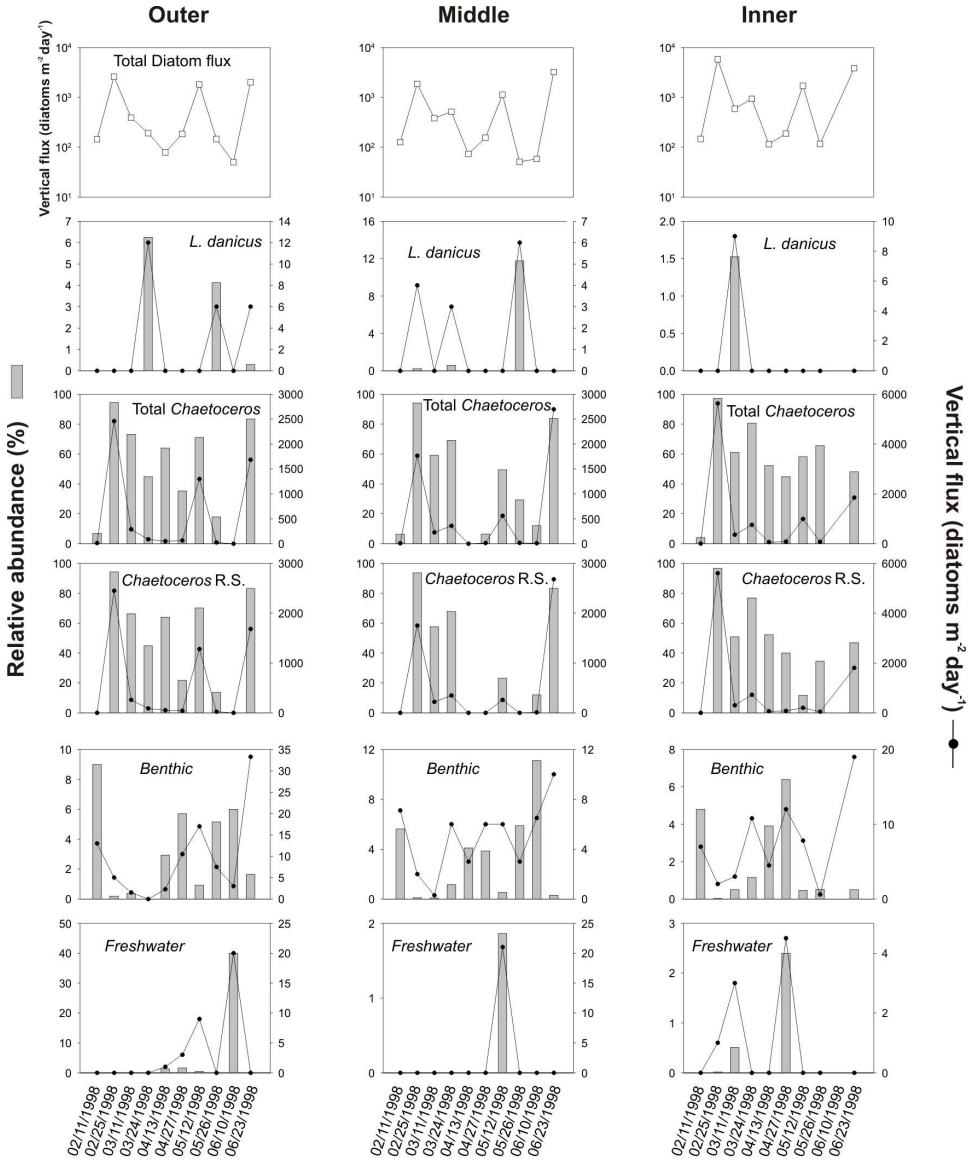

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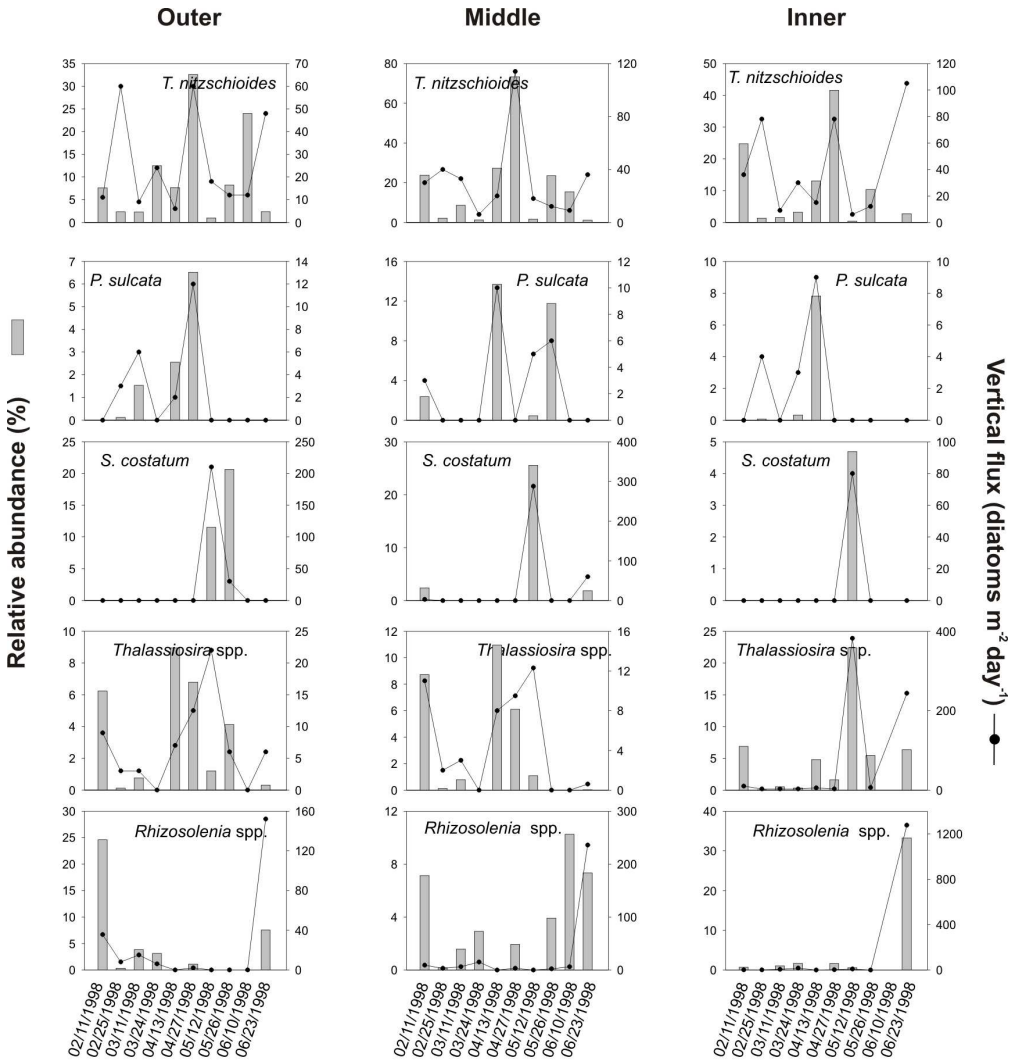

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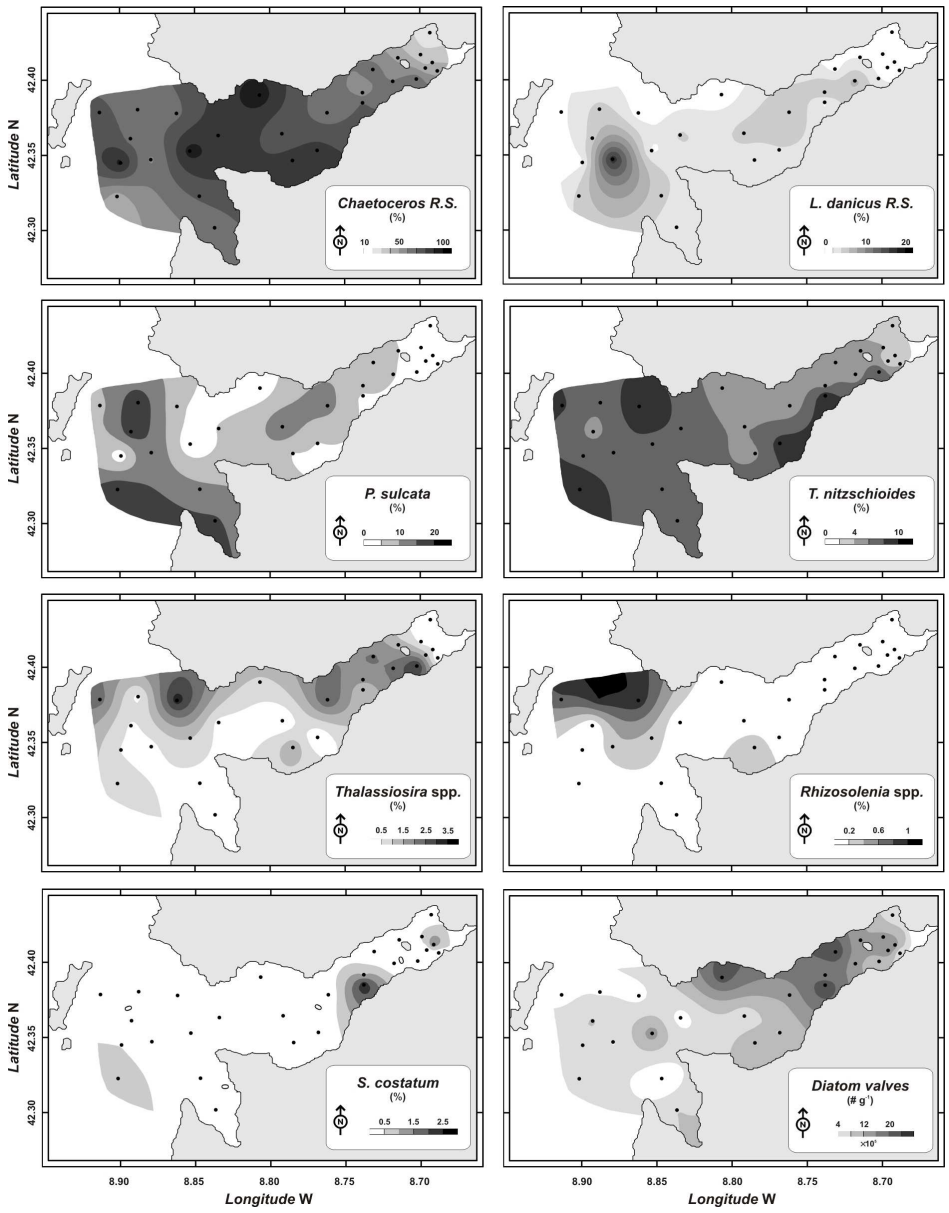

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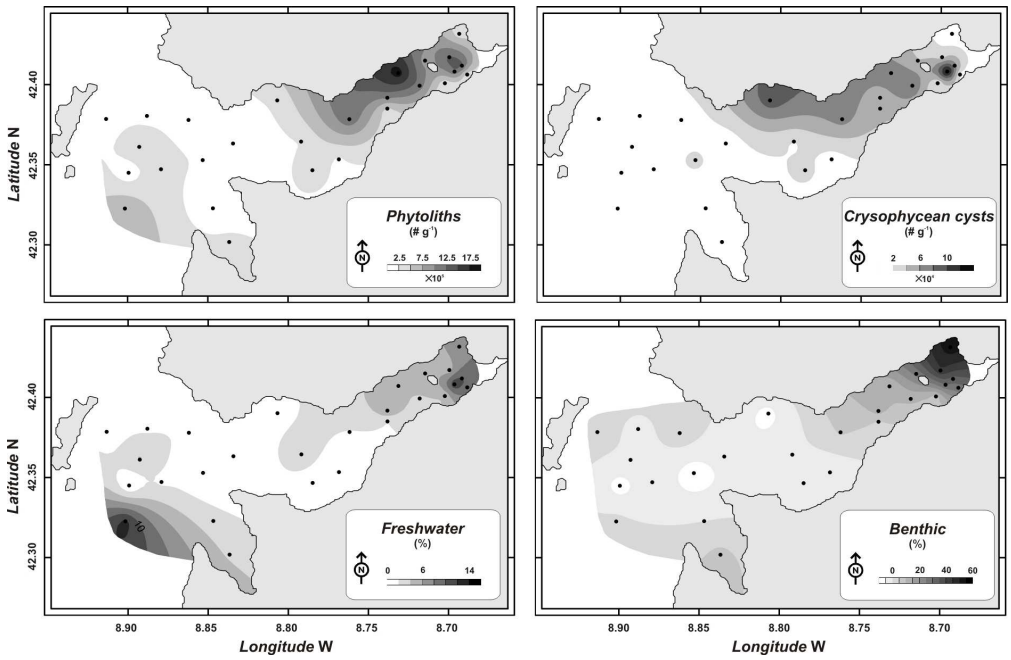

159x103mm (300 x 300 DPI)

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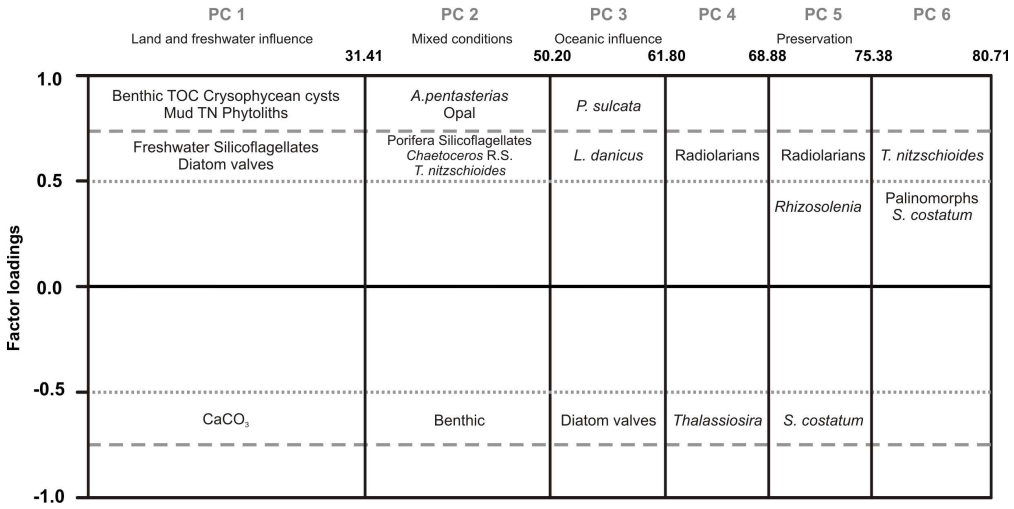

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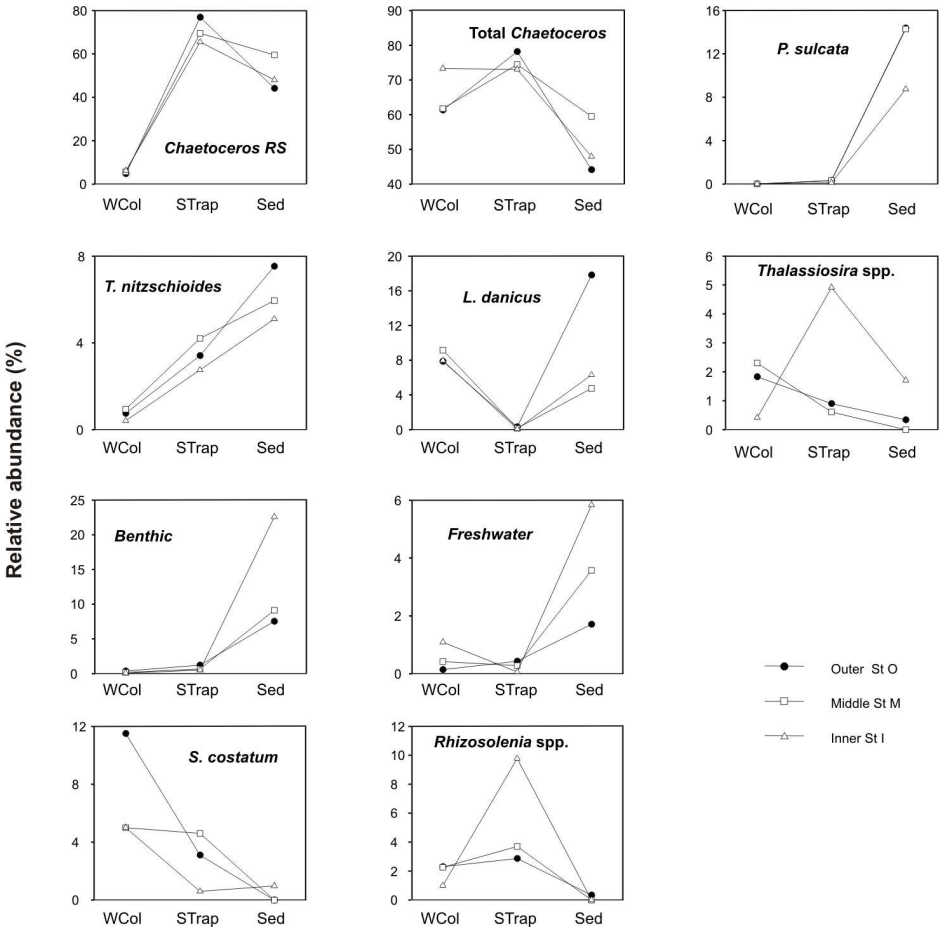

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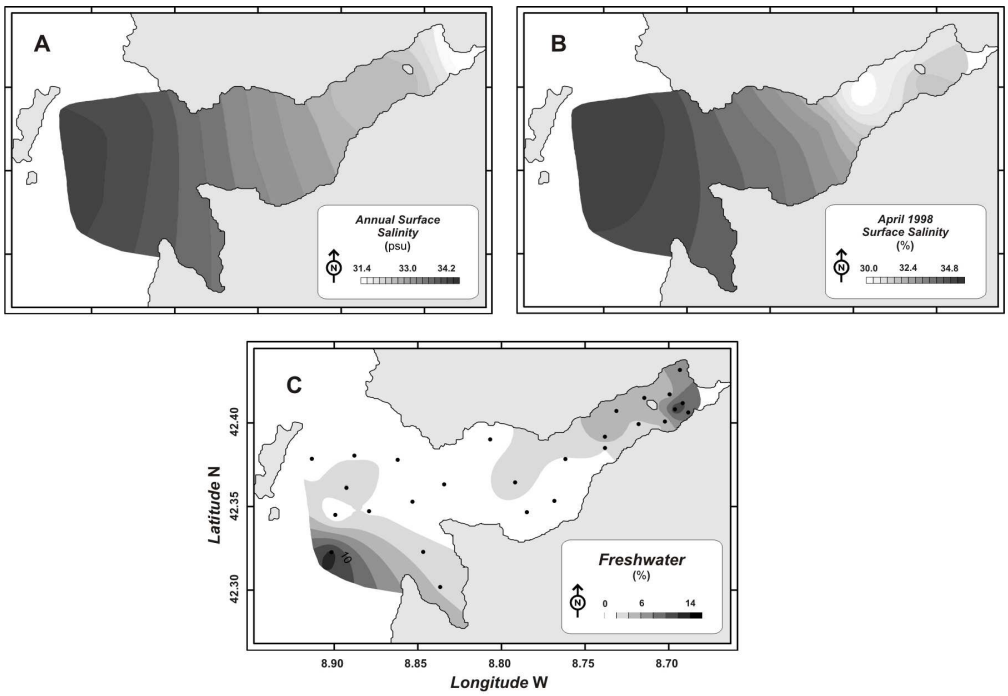

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